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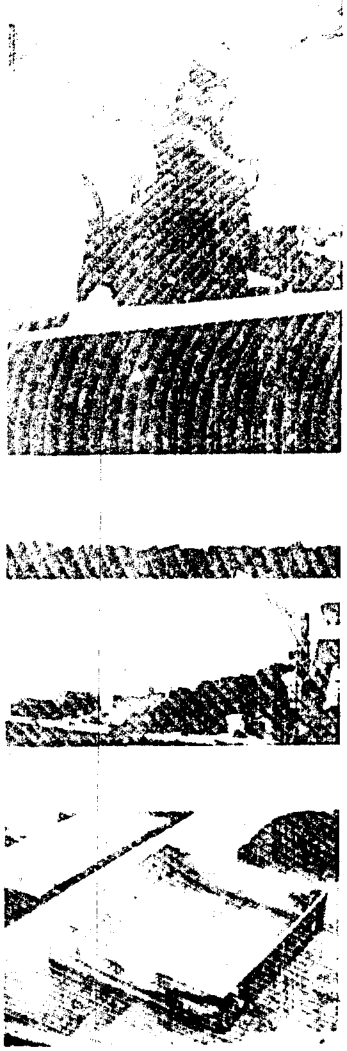

TECHNICAL REPORT EL-92-23

THE EFFECTS OF INCREASED COMMERCIAL NAVIGATION TRAFFIC ON FRESHWATER MUSSELS IN THE UPPER MISSISSIPPI RIVER: 1990 STUDIES

by

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In 1988 the US Army Engineer District, St. Louis, initiated a program to analyze the effects of commercial navigation traffic on freshwater mussels (Mollusca: Unionidae), especially the endangered _Lampsilis higginsi_, in the upper Mississippi River. Preliminary studies were conducted in 1988; detailed studies were initiated in 1989 and will continue for at least 6 years. In July 1990, mussels were collected using qualitative and quantitative (0.25 sq m total substrate) methods at dense and diverse beds in Pool 17 (RM 450.4 and 448.7) and Pool 12 (RM 571.5). Water velocity and suspended solids concentrations were measured immediately following vessel passage at sites where mussels were collected. An assessment of commercial navigation traffic effects will be based on a comparison of baseline data (1989-94) with data collected during periods of increased traffic intensity following 1994.

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PREFACE

In accord with the Endangered Species Act, Section 7 Consultation, personnel from the US Army Engineer District, St. Louis (CELMS), and the US Fish and Wildlife Service (USFWS) determined that a monitoring program should be initiated to assess the effects of existing and future increased traffic levels on freshwater mussels including L. higginsi. Concern had been expressed by the USFWS and other agencies that projected increases in commercial traffic resulting from completion of the Melvin Price Locks and Dam, Second Lock Project, Alton, IL (formally known as Locks and Dam 26), could negatively affect freshwater mussels. In 1988 the CELMS contracted with the US Army Engineer Waterways Experiment Station (WES) to initiate these studies. The purpose of 1988 studies was to identify sample sites for future work. This report describes results of the second full study year, which took place in 1990.

Divers for this study were Messrs. Larry Neill, Mitchell Marks, Steve McKinny, and Dennis Baxter, Tennessee Valley Authority. Messrs. Dan Ragland and Leo Nico, CELMS, and Mr. Robert Read, Wisconsin Department of Natural Resources, assisted in the field. Ms. Sarah Wilkerson, Jackson State University, Jackson, MS, prepared all figures except maps, and Dr. Ken Gordon, Training/Resource Consultants, Inc., Jackson, MS, analyzed shell and tissue condition. Comments on an early draft of this report were provided by Mr. Ragland and personnel of the Illinois Natural History Survey.

During the conduct of these studies at WES, Dr. John Harrison was Chief, Environmental Laboratory, Dr. C. J. Kirby was Chief, Environmental Resources Division, and Dr. E. A. Theriot was Chief of the Aquatic Habitat Group. Authors of this report were Drs. Andrew C. Miller and Barry S. Payne, EL.

At the time of publication of this report, Director of WES was Dr. Robert W. Whalin. Commander and Deputy Director was COL Leonard G. Hassell, EN.

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CONTENTS

CONVERSION FACTORS, NON-SI TO SI UNITS OF MEASUREMENT

Non-SI units of measurement used in this report can be converted to SI units as follows:

Multiply	By	To Obtain
cubic feet	0.02831685	cubic meters
degrees (angle)	0.01745329	radians
feet	0.3048	meters
inches	2.54	centimeters
miles (US statute)	1.609347	kilometers

THE EFFECTS OF INCREASED COMMERCIAL NAVIGATION TRAFFIC ON FRESHWATER MUSSELS IN THE UPPER MISSISSIPPI RIVER: 1990 STUDIES

PART I: INTRODUCTION

Background

1. Operation of the second lock at the Melvin Price Locks and Dam (formerly the Locks and Dam 26 (Replacement) project) will increase the capacity for commercial navigation traffic in the upper Mississippi River (UMR). Increased commercial traffic could detrimentally affect freshwater mussels (Mollusca: Unionidae), including *Lampsilis higginsi*, listed as endangered by the US Fish and Wildlife Service (1987). In accordance with the Endangered Species Act, Section 7 Consultation, personnel from the US Army Engineer District, St. Louis (CELMS), and the US Fish and Wildlife Service (USFWS) determined that a monitoring program should be initiated to assess the effects of projected traffic levels on freshwater mussels including *L. higginsi*. Other agencies that participated in the development of this program included the US Army Engineer Divisions, Lower Mississippi Valley and North Central; US Army Engineer Districts, St. Paul and Rock Island; and state conservation agencies and interested lay personnel.

2. A reconnaissance survey to choose sample sites was conducted in 1988 (Miller et al. 1990), with limited site-selection studies also conducted in 1989 (Miller and Payne 1991). Detailed studies at mussel beds (which included quantitative and qualitative sampling) were initiated in 1989 and will continue through 1994 to obtain baseline data. Between 1995 and 2040 studies are to be conducted every 5th year. This report contains a summary of data collected during the summer of 1990, the second full year of the project.

Study Design

3. This research was designed to obtain information on physical effects of commercial vessel passage (changes in water velocity and suspended solids near the substrate-water interface) at dense and diverse mussel beds in the UMR. In addition, important biotic parameters (species richness, species diversity, density, growth rate, population structure of dominant mussel

species, etc.) will be monitored every second year at these beds. The objective is to couple biological and physical studies so that reliable predictions of the physical effects of vessel passage can be made. At each mussel bed physical and biological data are being collected at a farshore (experimental) and a nearshore (reference) site. Experimental sites are located near the navigation channel (affected by vessel passage), and reference sites are located as far as possible from the channel (affected to a lesser extent by vessel passage).

4. Data are being collected to determine if commercial navigation traffic is negatively affecting _L. higginsi_. This is being accomplished by collecting information on all bivalve species. As appropriate, results will be applied to _L. higginsi_. This surrogate species concept is being used since it is extremely difficult to obtain information on density, recruitment, or other biotic parameters for uncommon species such as _L. higginsi_. In addition, intensive collections of this species would be detrimental to its continued existence.

5. Results of the reconnaissance survey in 1988 (Miller et al. 1990), and an additional 6 years (1989-94) of detailed study will provide baseline physical and biological information. Information obtained from studies to be conducted in 1995-2040 will be compared with results of baseline studies to determine if commercial traffic is having negative biological effects. The following six parameters, considered to be indicative of the health of a mussel bed, will be used to determine if commercial navigation traffic is negatively affecting freshwater mussels:

a. Decrease in density of five common-to-abundant species.

b. Presence of _L. higginsi_.

c. Live-to-recently-dead ratios for dominant species.

d. Loss of more than 25 percent of the mussel species.

e. Evidence of recent recruitment.

f. A significant change in growth rates or mortality of dominant species.

6. Each mussel bed will be studied every other year until 1994; therefore, three nonconsecutive years of data will be collected at each location. Data will be collected during a period when traffic levels are not expected to increase. After 1994, biological and physical data will be collected at each bed once every 5 years. This will be done until traffic levels have increased by an average of one tow per day above 1990 levels in the pool where

monitoring takes place. Studies will then resume at the original rate and continue until 2040, the economic life of the Melvin Price Locks and Dam Project. Results of these studies will be reviewed annually to determine the need for altering sampling protocol. A preliminary schedule of studies to be conducted at each mussel bed appears in Table 1. A more complete description of these studies appears in Miller et al. (1990). Results of the 1989 study year appears in Miller and Payne (1991).

Table 1

Summary of Biological and Physical Studies Conducted in the Navigation Traffic Effects Study, Upper Mississippi River, 1988-94

		Fiscal Year						
Pool	RM	88	89	90	91	92	93	94
24	299.4	Qual	Qual		Qual		Qual	
		Quant	Quant		Quant		Quant	
					Growth------	------------	------------	------------
					Physical			
17	450.4	Qual		Qual		Qual		Qual
		Quant		Quant		Quant		Quant
				Growth------	------------	------------	------------	------------
				Physical				
14	504.8	Qual	Qual		Qual		Qual	
		Quant	Quant		Quant		Quant	
			Growth------	------------	------------	------------	------------	------------
			Physical		Physical			
12	571.5		Qual	Qual		Qual		Qual
				Quant		Quant		Quant
				Growth------	------------	------------	------------	------------
				Physical				
10 (MC)	634.7	Qual	Qual		Quant		Quant	
			Quant		Qual		Qual	
			Growth------	------------	------------	------------	------------	------------
			Physical		Physical			

Note: Quant - Quantitative samples
Qual - Qualitative samples
Growth - Marked mussels are placed for analysis of rate of growth
Physical - Measures of water velocity and total suspended solids following passage of a commercial vessel
MC - Main channel

River miles may differ slightly from those in previous reports. These mussel beds can be several miles long, and sites can vary a few tenths of a mile from year to year.

Purpose and Scope

7. The purpose of this research (1989-94) is to obtain baseline data on physical (water velocity and suspended solids) and biological conditions (density, species richness, relative species abundance, population demography of dominant species, etc.) at five mussel beds between river mile (RM) 299 and 635 in the UMR. The purpose of the 1990 studies was to collect biological and physical data at a mussel bed in Pool 17 (sites were at RM 448.7 and 450.4) and at a bed in Pool 12 (RM 571.5).

PART II: STUDY AREA AND METHODS

Study Area

8. The UMR was once a free-flowing, braided, pool-riffle habitat with side channels, sloughs, and abandoned channels. This habitat was altered as a result of passage of the Rivers and Harbors Act of 3 July 1930 which authorized the US Army Corps of Engineers to construct a navigation channel with a minimum depth of 9 ft and a minimum width of 300 ft. Development of this navigation channel, which included placement of locks, dams, dikes, wing dams, and levees, converted the river to a series of run-of-the-river reservoirs. These reservoirs were characterized by relatively slow-moving water and extensive adjacent lentic habitats. Typically, the upper reaches of pools in the UMR have relatively high-velocity water and riverine conditions, whereas the lower reaches are more lake-like with deep, low-velocity water and fine-grained sediments (Eckblad 1986).

9. At sites investigated for this study, substrate in Pools 26-24 consisted mainly of coarse gravel, cobble, and slab rock. The channel was fairly narrow and deep, with comparatively few side channels, islands, or backwaters. Study sites in the middle reach of the UMR (Pools 22-17) were characterized by fine-grained sediments, numerous islands, sloughs, and backwaters. The upper reach of the river, at study sites in Pools 14, 12, and 10, was characterized by numerous islands, backwaters, sloughs, and beds of aquatic macrophytes. Substrate usually consisted of fine-grained sand and silt.

Study Sites

10. In 1988 preliminary data on physical and biological conditions were collected at mussel beds in Pools 26, 25, 24, 19, 18, 17, 14, 10, and 7. In 1989 additional preliminary studies were conducted in Pools 12 and 13. In these surveys a combination of qualitative and quantitative techniques were employed to determine if the bed was suitable for detailed study. Based on information from these surveys, five mussel beds were chosen (Table 1, Figure 1).

11. The mussel beds chosen for study by representatives of the St. Louis District, US Army Engineer Waterways Experiment Station (WES), and USFWS are:

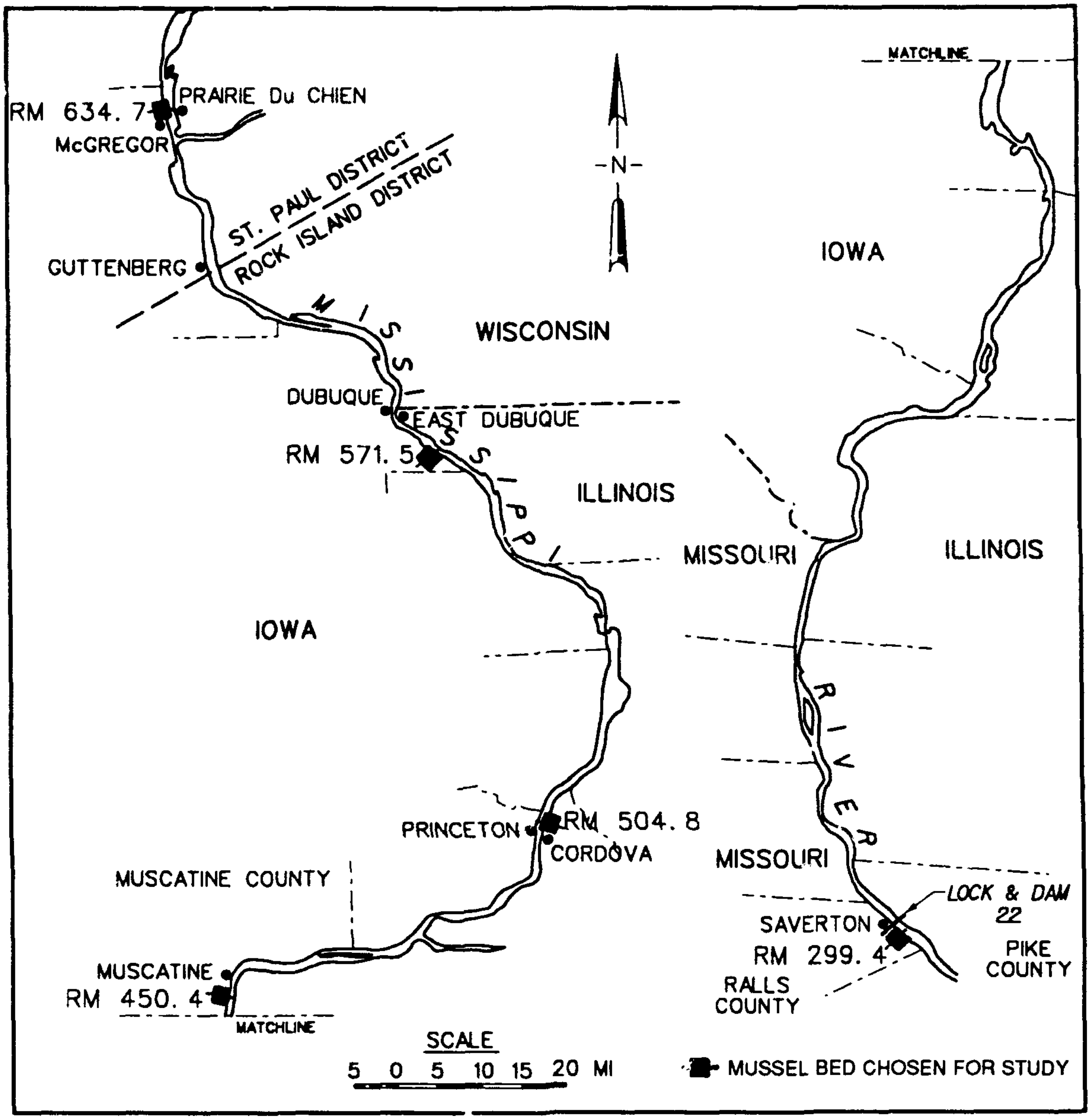


Figure 1. Location of the five mussel beds chosen for detailed study in the UMR, 1989-1994

Pool	RM
24	299.4 RDB*
17	450.4 RDB
14	504.8 LDB*
12	571.5 RDB
10	634.7 RDB

A complete description of mussel beds in Pools 24, 14, and 10 appears in the study by Miller and Payne (1991); the following applies only to the beds studied in 1990:

Pool 17

12. In 1988 a single L. higginsi was found in a qualitative sample of 567 individuals at a bed in Pool 17 (Miller et al. 1990) (Figure 2). Twenty quantitative samples were then collected at RM 450.4; however, no L. higginsi were found. Because of the interest in having a monitoring site in the middle reach of the UMR (Pools 17-19), this mussel bed was considered for detailed study. During this survey (1991), additional reconnaissance was conducted at this site. Although L. higginsi was extremely uncommon, this bed was chosen for study since it contained a dense and diverse assemblage of mussels in close proximity to the navigation channel. In this study year (1990) quantitative samples were taken at RM 450.4.

Pool 12

13. The results of preliminary sampling in 1988 indicated that a mussel bed at RM 571 would be suitable for detailed study (Miller et al. 1990) (Figure 3). The bed is long and narrow and located on the right descending bank (RDB) immediately downriver of a sharp left turn. Commercial traffic moving up or downriver approach the RDB (and the mussel bed) as they enter or exit the turn. Based on the 1988 survey, densities appeared to be moderate to high with good species richness. A single L. higginsi was found in a qualitative collection of 158 individuals. In this study year (1990) quantitative samples were taken at RM 571.5.

Methods

Preliminary reconnaissance

14. Before intensive sampling at a mussel bed was initiated, a diver equipped with surface air made a preliminary survey. He obtained information on substrate type, water velocity, and presence of mussels. A fathometer was

* RDB = Right descending bank; LDB = Left descending bank

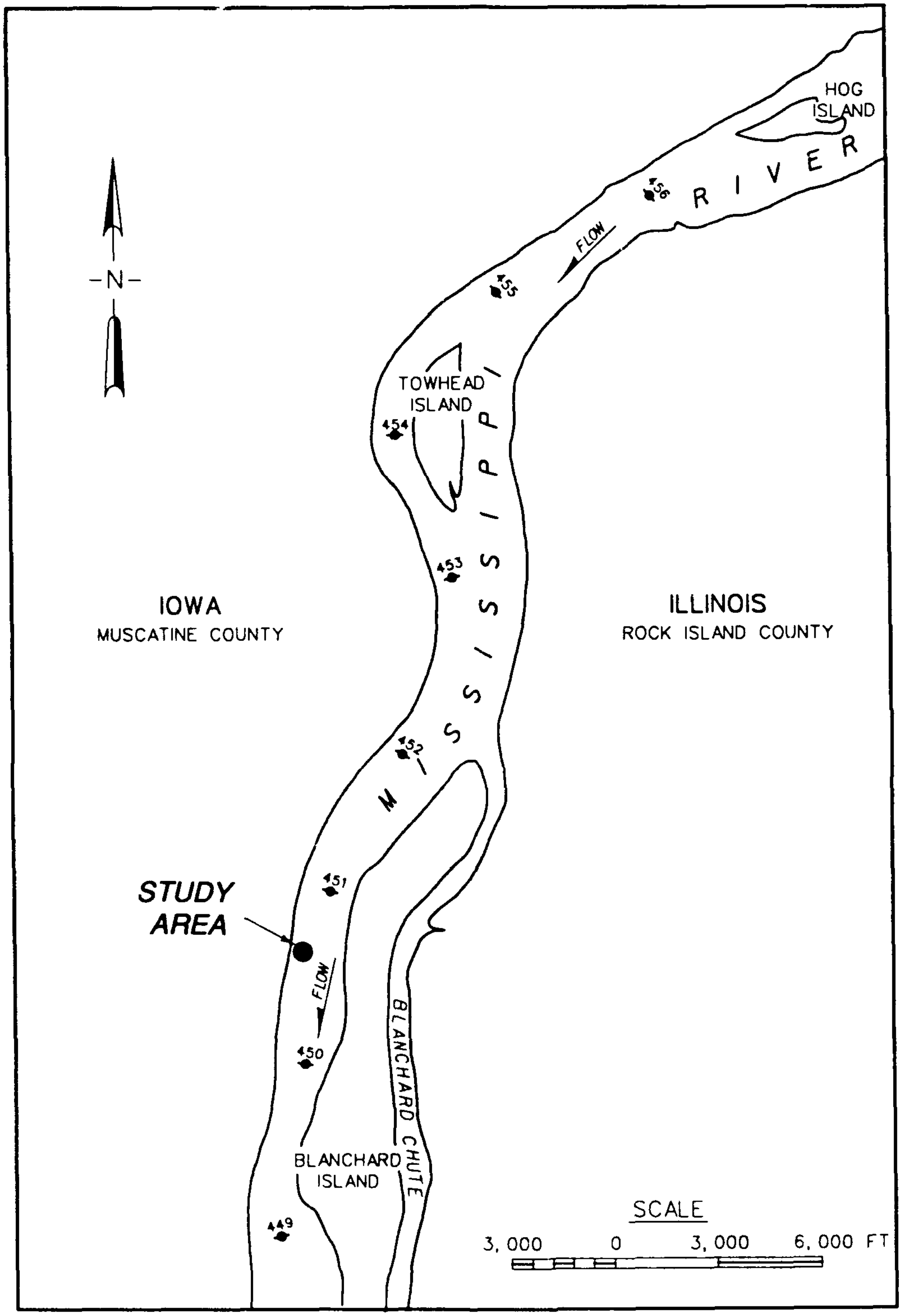


Figure 2. Study area at the mussel bed located in Pool 17, RM 450.

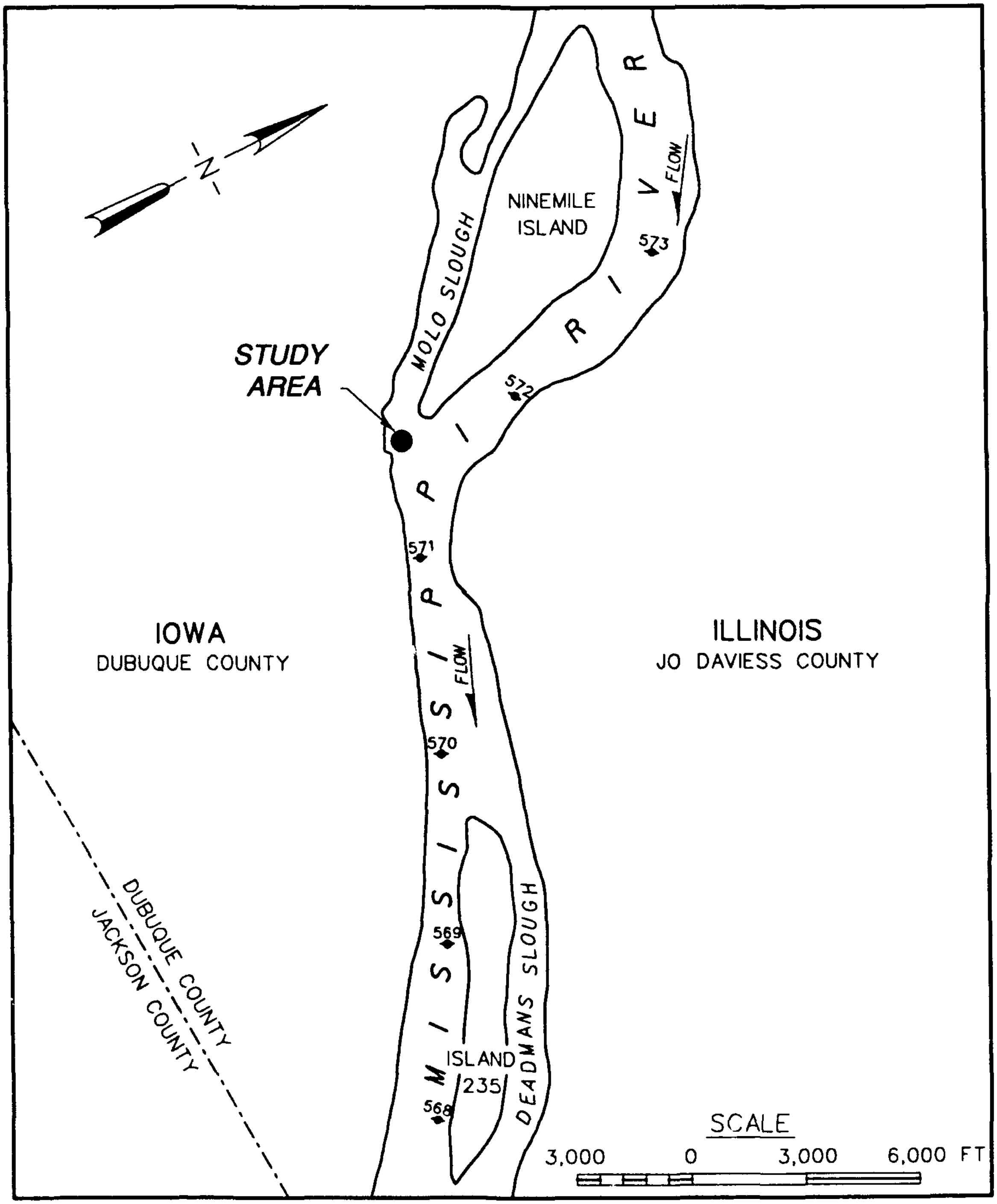


Figure 3. Study area at the mussel bed located in pool 12, RM 571.

used to measure water depth, and distance to shore was determined with an optical range finder. If the site appeared suitable, then detailed studies were initiated.

Qualitative collections

15. Qualitative collections were made at suitable sites by one or more divers equipped with surface air supply (Table 2). Divers were instructed to search for and retain all live mussels until a sample of approximately 5 (first bag) or 20 individuals (second and third bags) was obtained. Usually at least nine samples, held in nylon bags, were obtained at each site. Collecting was done mainly by feel, since water visibility was poor. Mussels were brought to the boat and identified. Selected individuals were shucked and retained for voucher. Additional specimens were preserved in 10-percent buffered formalin and returned to the laboratory for analysis of physical condition (ratios of shell length to tissue dry mass, etc.). Unneeded specimens were returned to the river unharmed.

Quantitative sampling

16. At each site ten 0.25-m^2 quadrat samples were obtained at each of three subsites separated by 5-10 m. At each subsite, quadrats were placed

Table 2

Quantitative and Qualitative Mussel Collections in the UMR, 1990

River* Mile	Subsite	Distance to shore, ft	Depth ft	Qualitative Samples	Quantitative Samples
		9-12 July 1990, Pool 17			
448.7	A	220	16	9	--
448.7	B	160	12	12	--
450.4	A	150	20	12	--
450.4	B	50	15	20	--
450.4	A	75	13	--	30
450.4	B	120	15	--	30
		14-17 July 1990, Pool 12			
571.5	A	200	10	12	--
571.5	B	325	25	12	--
571.5	C	350	21	12	--
571.5	A	140	15	--	20
571.5	B	200	23	--	20
571.5	C	350	32	--	20

* All samples taken along right descending back up the river.
Note: Double dash (--) indicates that no samples were taken.

approximately 1 m apart and arranged in a 2- by 5-m matrix. A diver removed all sand, gravel, shells, and live molluscs within the quadrat. It usually took 5-10 min to clear the quadrat to a depth of 10-15 cm. All material was sent to the surface in a 20-l bucket, taken to shore, and sieved through a nested screen series (finest screen with apertures of 6.4 mm) and picked for live organisms. All bivalves were identified, weighed to the nearest 0.01 gm on an electric top-loading balance, and total shell length (SL) was measured to the nearest 0.1 mm. All L. higginsi were returned to the river unharmed. Some of the bivalves were measured in the evening then returned to the river the next day. Bivalves that could not be processed were preserved in 10-percent buffered formalin and were taken to WES for analysis. Notes were made on the number of "fresh dead mussels" (defined as dead individuals with tissue still attached to the valves).

17. At RM 450.4 thirty samples were taken at a nearshore (75 ft from the RDB) and a farshore location (120 ft from RDB). At RM 571.5 twenty quantitative samples were taken at three locations, 140, 200, and 350 ft from the RDB. This was done since the densities at the nearshore site were unusually low. It was later determined that low density was probably the result of reduced current velocities because of protection from an exposed shoal immediately downriver.

Growth Studies

18. In 1989 growth studies were initiated in Pool 14 and the west channel of the UMR in Pool 10. Six demographically complete groups of three unionid species were collected for growth studies. Each group contained 20 Amblema plicata, 20 Quadrula pustulosa, and 5 Obliquaria reflexa. Shell length was measured in the field and each mussel was engraved using a dremel tool with an identifying letter. At each site, three 0.25-m^2 aluminum quadrats were cabled together with 20 m of 3/8-in. coated wire rope. The quadrats were secured to the river bottom, and all substrate (i.e. live bivalves, sand, and gravel) was excavated to a depth of 10-15 cm. Twenty liters of screened gravel (saved from the quantitative samples) and the marked mussels were placed in each quadrat.

19. In 1990 these sites were revisited and searches were made for marked and measured mussels. None of the quadrats were found, although some of the concrete blocks were recovered. It appeared that the quadrats had been removed by commercial divers or fishermen. During the summer of 1990, additional mussels were marked and more quadrats were placed. Because of the poor

success in retrieving the quadrats placed in 1989, different procedures were used in 1990. In the present study year the cable was buried beneath the surface so it would be less likely to be snagged by grappling hooks. Additional options to assist with successfully relocating the quadrats will be employed in 1991. These will include: marking the sites with a small radio transmitter so that wire rope (which is easily snagged by commercial fishermen) will not have to be used, and use of a Loran positioning device.

Water velocity readings

20. Water velocity was measured 23 cm above the substrate-water interface using a Marsh McBirney Model 527 current meter. The sensor for this instrument measures velocity in two directions (an X and Y component that are at right angles to each other) and is equipped with a compass. The compass, which is read from the meter, assists in positioning the sensor and can be used to calculate direction of flow. The meter sensor was mounted in a concrete block, positioned and secured by divers. Two meters were equipped with 1,000 ft of cable, and two were equipped with 200 ft of cable. Water velocity in two directions and a compass reading were obtained at 1-sec intervals and stored on a model CR10 data logger (Campbell Scientific, Inc., Logan, UT). Data were downloaded to a Toshiba lap-top personal computer for later analysis and plotting.

21. During 1990 the effects of commercial vessel passage on water velocity was studied at two mussel beds. Data were collected along the RDB at RM 450.4 (Pool 17) and RM 571.5 (Pool 12). Up to four sensors were deployed, at distances ranging from 70 to 460 ft from the bank. Sensors were never placed in the navigation channel. Each sensor was positioned to obtain velocity readings parallel to (pointing upriver) and at right angles (pointing into the channel) to the direction of flow.

22. The sensors were positioned at the beginning of the day and retrieved every evening. When a commercial vessel was sighted the meters and data logger were turned on (usually about 250 sec before the vessel passed), and continuous data on water velocity and compass readings were obtained. Usually between 600 and 1,200 sec of data were collected for each vessel passage. Data on type of vessel, distance to shore, direction, etc. were recorded.

23. Velocity data and compass readings were converted to ASCII files and magnitude of flow was calculated from individual velocity components by the formula:

$$\text{Magnitude} = (X^2 + Y^2)^{0.5}$$

The resolved angle of water flow was determined by the formulae:

$$0 = TAN^{-1}\ (X/Y) \quad \text{if } Y \geq 0, \text{ or}$$

$$0 = TAN^{-1}\ (X/Y) + 180°, \text{ if } Y < 0$$

24. Summary statistics (mean, standard deviation, minima, and maxima) were calculated for a time interval immediately before and during each event. The time interval before the event included 100-200 sec that ended at least 50 sec before the vessel reached the site. The time interval that included the event usually began 50 sec before the vessel reached the sensors and continued for at least more than 150 sec. The magnitude of physical change associated with each passage could then be evaluated by comparing summary statistics collected during the event with statistics obtained before the vessel passed.

Turbidity

25. Water for suspended solids was collected 10 cm above the substrate-water interface at the same locations where velocity was measured. Water was brought to the surface through a 25-ft length of rubber hose secured to a concrete block. Suction was provided by a 12-volt Water Puppy Pump. The pump ran continuously and a 500-ml bottle was filled every 2 min. Turbidity was determined in the field with a Hach portable turbidimeter.

Data Analysis

26. All bivalve data (lengths, weights, etc.) were entered on a spread sheet and stored in ASCII files. Summary statistics were calculated using functions in the spread sheets or with programs written in BASIC or SAS. All computations were accomplished with an IBM or compatible XT or AT personal computer. Biological and physical data were plotted directly from ASCII files using a Macintosh SE computer and a laser printer.

PART III: THE BIVALVE COMMUNITY

Community Characteristics-Qualitative Data

27. A total of 1,323 bivalves was collected in 89 separate qualitative samples at sites in Pools 17 and 12 in July, 1990 (Table 3, Tables A1-A6 in Appendix A). *Amblema plicata* dominated, comprised 30.76 percent of the collection, and was found in 86.52 percent of the samples. Plotting the relative abundance of each species versus its rank for the entire qualitative collection, Figure 4 illustrates that the assemblage spanned four orders of magnitude. *Amblema plicata* was approximately three times as abundant as the next common species, *Megalonaias nervosa*, which comprised 10.51 percent of the fauna. Fifteen species were common and comprised from 8.39 to 1.28 percent of the collection and six species made up less than 1 percent of the assemblage. Although 23 species were collected, more than 50 percent of this fauna consisted of four species (Figure 4 and Table 3); the majority of the bivalves collected in 1990 can be considered either common or very uncommon.

28. The relationship between percentage abundance and species rank for the qualitative collection at each of the three sites studied in 1990 (RM 448.7, RM 450.4, and RM 571.5) appears in Figure 5 (see Appendix A, Tables A1-A6). The collection from RM 571.5 was characterized by stronger dominance of a single species (*A. plicata*) than at the two sites near RM 450.4. Aside from this difference, distribution of species within the assemblage was relatively similar at both beds.

29. Based on the qualitative samples, there were differences in relative abundance of common to abundant species at near versus farshore sites at RM 448.7 and 450.4 (Figure 6). *Amblema plicata* was consistently dominant at nearshore sites; whereas *Lampsilis ventricosa*, *Obovaria olivaria*, and *Quadrula metanevra* dominated at farshore sites. The other species depicted in Figure 6 (*M. nervosa*, *Leptodea fragilis*, *Potamilus alatus*, and *O. reflexa*) showed no consistent nearshore/farshore trends at the bed site in Pool 17. In Pool 12 (RM 571.5) *A. plicata* dominated close to shore and *L. ventricosa* dominated farther from shore (Figure 7). In this regard, the site in Pool 12 was similar to the site in Pool 17.

30. A plot of cumulative species versus cumulative individuals (referred to as species-area curves) provides a mechanism for determining the difficulty of obtaining rare species (Figure 8). At the three sites where

Table 3

Relative Abundance (p_i) and Frequency of Occurrence (f_i) of Freshwater Mussels Collected Using Qualitative Techniques in the Upper Mississippi River, July 1990

Species	Individuals	p_i*	Samples	f_i**
Amblema plicata (Say 1817)	407	0.3076	77	0.8652
Megalonaias nervosa (Rafinesque 1820)	139	0.1051	54	0.6067
Quadrula pustulosa (Lea 1831)	111	0.0839	51	0.5730
Leptodea fragilis (Rafinesque 1820)	111	0.0839	35	0.3933
Quadrula quadrula (Rafinesque 1820)	85	0.0642	43	0.4831
Lampsilis ventricosa (Barnes 1823)	64	0.0484	38	0.4270
Ellipsaria lineolata (Rafinesque 1820)	64	0.0484	36	0.4045
Obovaria olivaria (Rafinesque 1820)	59	0.0446	31	0.3483
Potamilus alatus (Say 1817)	33	0.0249	21	0.2360
Fusconaia flava (Rafinesque 1820)	32	0.0242	20	0.2247
Actinonaias ligamentina (Lamarck 1819)	32	0.0242	23	0.2584
Anodonta grandis (Say 1829)	32	0.0242	20	0.2247
Quadrula metanevra (Rafinesque 1820)	32	0.0242	21	0.2360
Ligumia recta (Lamarck 1819)	31	0.0234	22	0.2472
Obliquaria reflexa (Rafinesque 1820)	26	0.0197	18	0.2022
Truncilla truncata (Lea 1860)	20	0.0151	15	0.1685
Arcidens confragosus (Say 1829)	17	0.0128	13	0.1461
Strophitus undulatus (Say 1817)	12	0.0091	11	0.1236
Lampsilis higginsi (Lea 1857)	5	0.0038	4	0.0449
Quadrula nodulata (Rafinesque 1817)	4	0.0030	3	0.0337
Anodonta corpulenta (Say 1824)	3	0.0023	2	0.0225
Lasmigona complanata (Barnes 1823)	3	0.0023	3	0.0337
Potamilus laevissima (Lea 1830)	1	0.0008	1	0.0112
Total bivalves 1,323				
Total species 23				
Total samples 89				

* p_i equals the number of individuals of species i divided by the total number of individuals collected.

** f_i equals the number of samples in which at least one individual of that species was collected divided by the total number of samples.

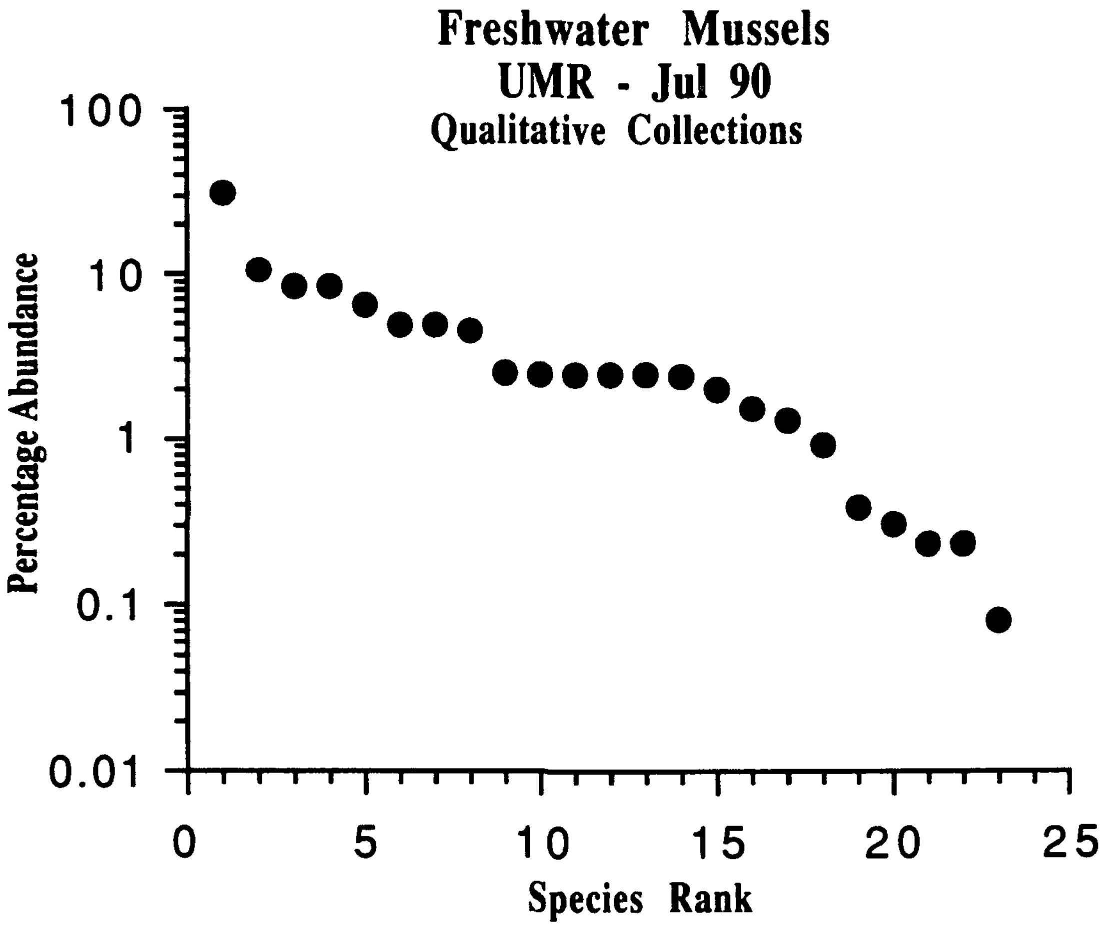


Figure 4. Percentage abundance versus species rank for all mussels collected using qualitative methods at RM 448.7, 450.4, and 571.5 in the UMR, 1990

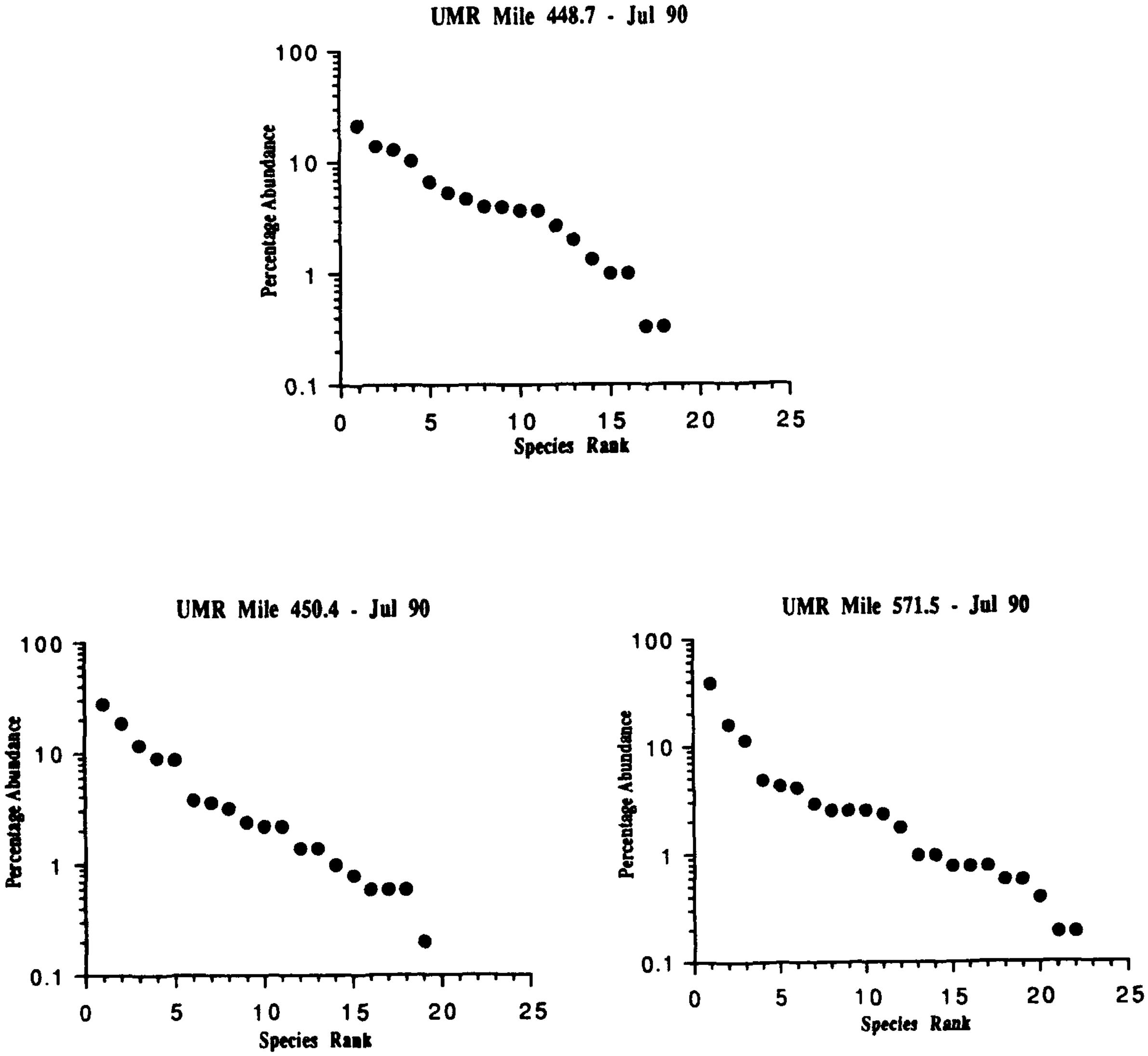


Figure 5. Percentage abundance versus species rank for mussels collected using qualitative methods at three locations in the UMR.

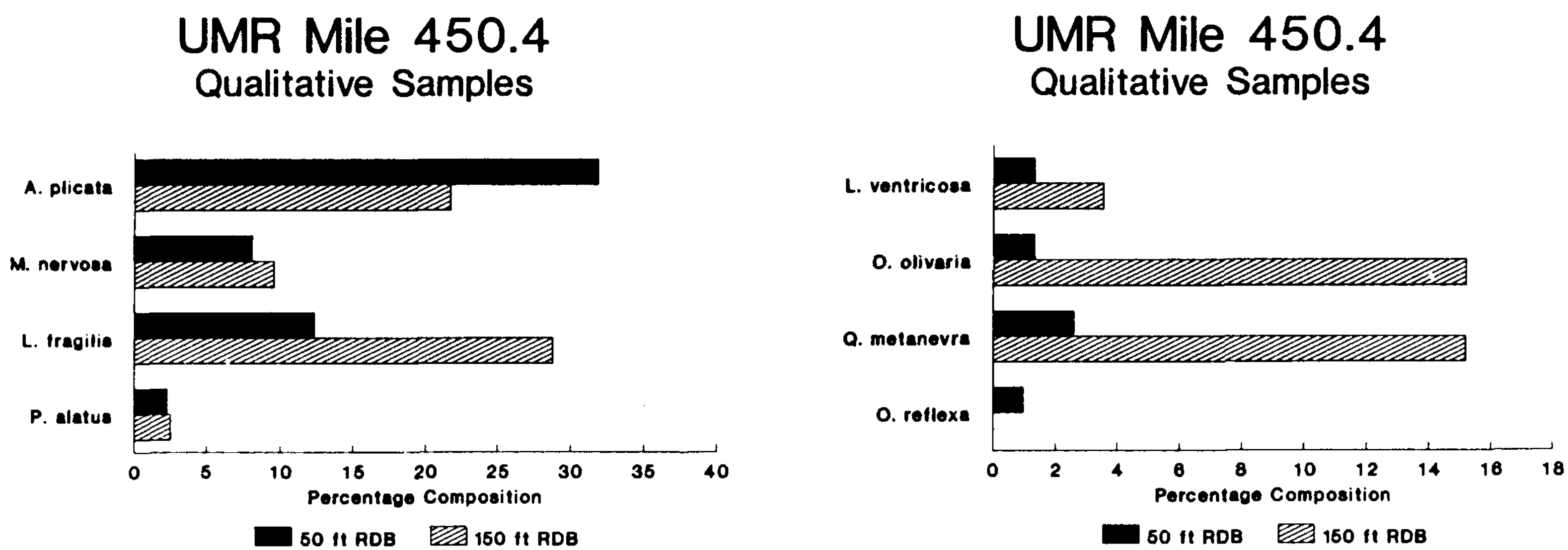


Figure 6. Relative abundance of common-to-abundant mussels at near and farshore sites at RM 450.4 based on qualitative sampling techniques

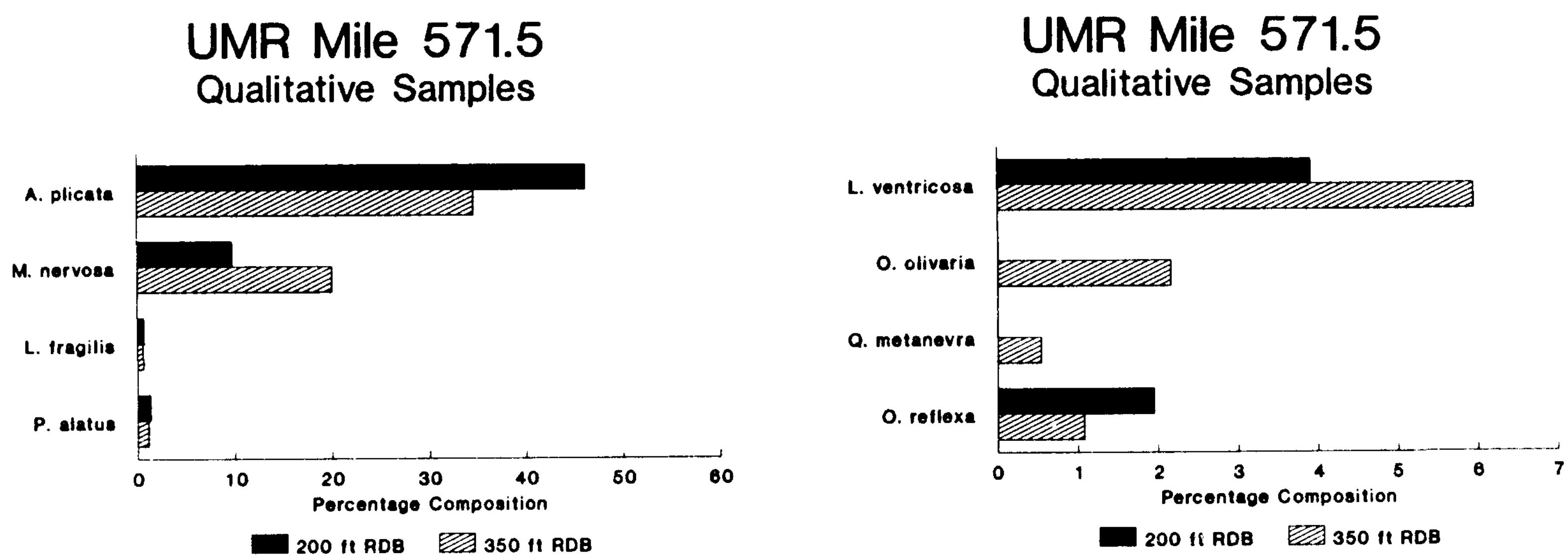


Figure 7. Relative abundance of common-to-.bundant mussels at near and farshore sites at RM 571.5 based on qualitative sampling techniques

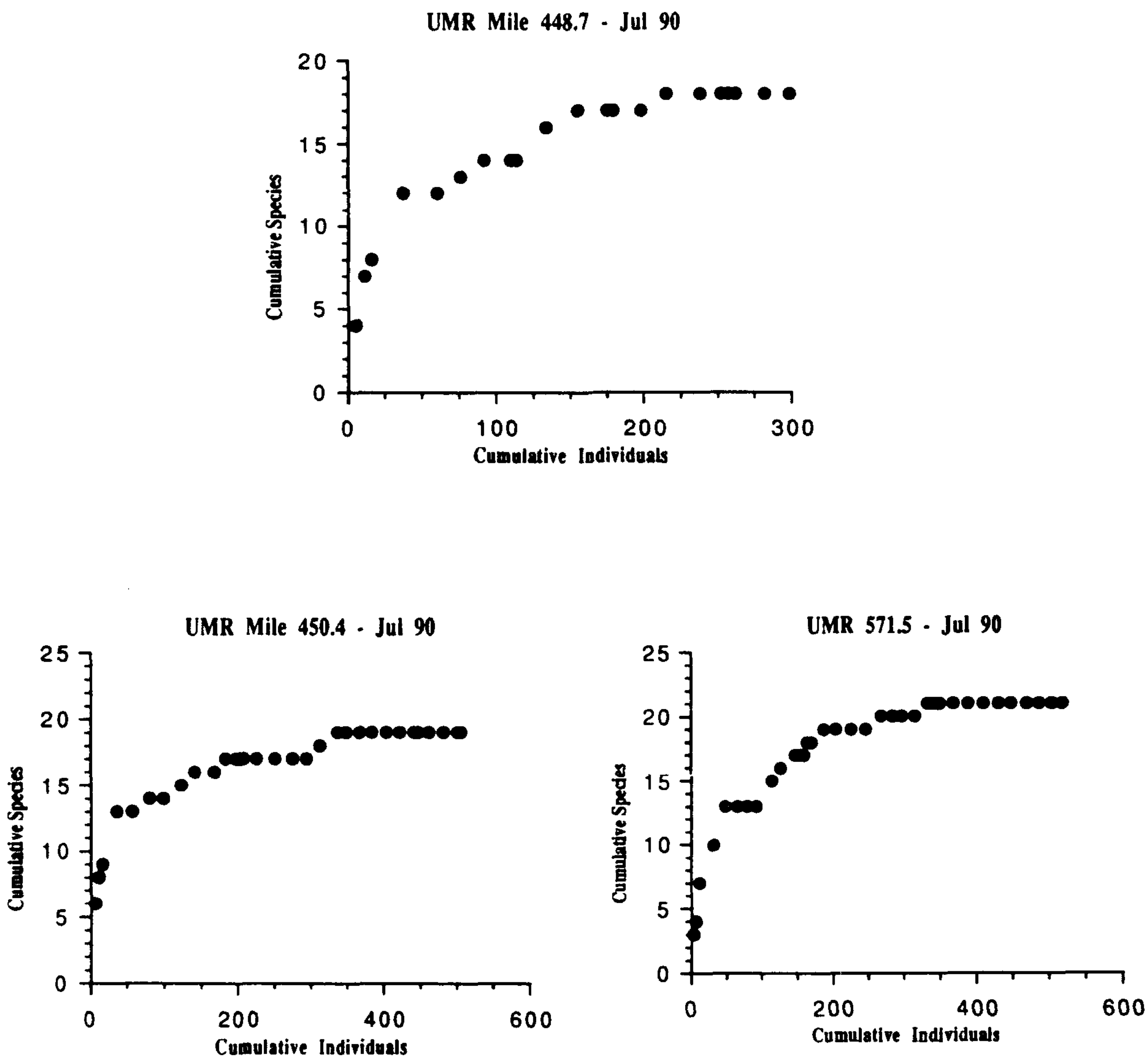


Figure 8. Cumulative species versus cumulative individuals based on qualitative sampling for freshwater mussels at three locations in the UMR, 1990.

qualitative samples were taken, these relationships indicated that the majority of species present were found after 200 individuals had been collected. It is, of course, possible that more species could have been found at these sites with more intensive sampling. If present, they would have comprised less than 0.2 percent of the assemblage. A determination of the relationship between species present and sampling effort provides an index of the ability to collect uncommon species that can be compared among years. These indices can be used to evaluate the effects of commercial navigation traffic or other factors that alter habitat.

Bivalve Density

31. A listing of species collected, percent abundances, and summary statistics for each quantitative collection appears in Tables B1-B5, Appendix B. At RM 450.4, total bivalve density at the nearshore site was greater than at the farshore site (86.8 individuals/sq m versus 58.5 individuals/sq m (Table 4 and Figure 9), and between site density differences were significant at the 0.05 level ($P = 0.0216$). There were also significant differences among sites ($P = 0.0001$) at RM 571.5 (Table 5, Figure 9, Appendix B). Density became significantly greater moving from nearshore (140 ft RDB) to farshore (350 ft RDB) at this mussel bed in Pool 12.

32. As the quantitative samples were processed, the number of fresh dead bivalves (individuals that were obviously dead but still had tissue within the valves) were enumerated (Table B6). As the results illustrate, there were few fresh dead mussels at either of these mussel beds. Analysis of future data on fresh dead shells will be used to assess the effects of commercial navigation traffic.

Community Characteristics-Quantitative Data

33. Species diversity (H') was low to moderate at RM 450.4 (2.38 and 2.47) and at RM 571.5 (1.36, 2.35, and 2.35, Tables B1-B5, Appendix B). Evenness (J), which can range from near 0 to near 1.0, ranged from 0.697 to 0.799 in Pool 12 and can be considered moderate to high. The number of individuals and species present that were less than 30 mm in total shell length can be used as an index of recent recruitment. At RM 450.4 there were

Table 4

Summary Statistics for Unionids (Average Density and Standard Error, (SE)) Collected in 0.25 m^2 Quadrats at RM 450.4R, Pool 17, UMR, 1990

Subsite	Distance to Shore, (ft)	Density, avg	SE
1	75	147.2	13.9
2	75	48.4	6.5
3	75	64.8	8.6
Total	75	86.8[A]	9.8
1	120	38.4	11.5
2	120	76.4	12.1
3	120	60.8	9.6
Total	120	58.5[A]	6.8
Analysis of Variance:			
	F*	PR>F**	
Between sites	5.58	0.0216	

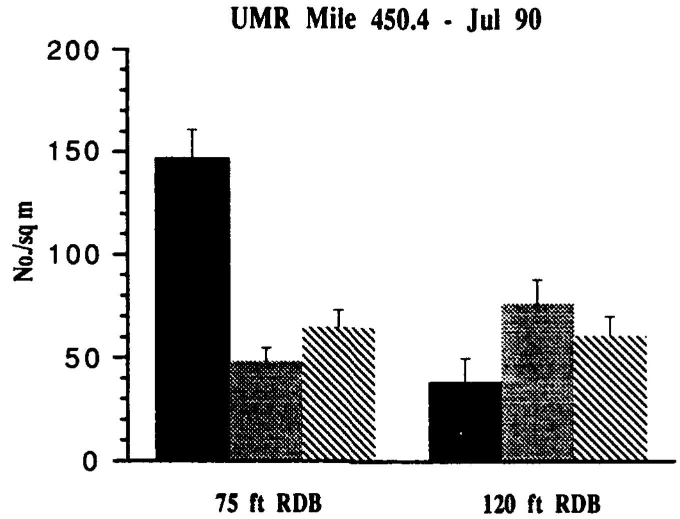
Note: Total density values (all subsites combined) with similar superscript letters are not significantly different at the 0.05 level.

* F Value from analyses of variance.

** Probability of a greater F value.

no trends with respect to distance from shore and small mussels comprised 12.0 to 13.7 percent of the assemblage (Tables B1 and B2, respectively). At RM 571.5 the smaller mussels comprised 44.9 percent of the assemblage at the nearshore site, 28.2 percent of the assemblage at the middle site, and 17.9 percent at the farshore site. At this location there was an inverse relationship between total bivalve density and percentage organisms less than 30 mm in total shell length. However, the actual density of small organisms at these three sites was similar and was not related to distance from shore (Figure 10).

34. Nearshore/farshore differences for common to abundant bivalves collected using quantitative methods was analyzed at RM 571.5 (Figure 11). Amblema plicata and O. reflexa were most common at the nearshore site. The Liliput shell (Toxolasma parva), which is commonly found in ponds and sloughs, was found only at the nearshore site.



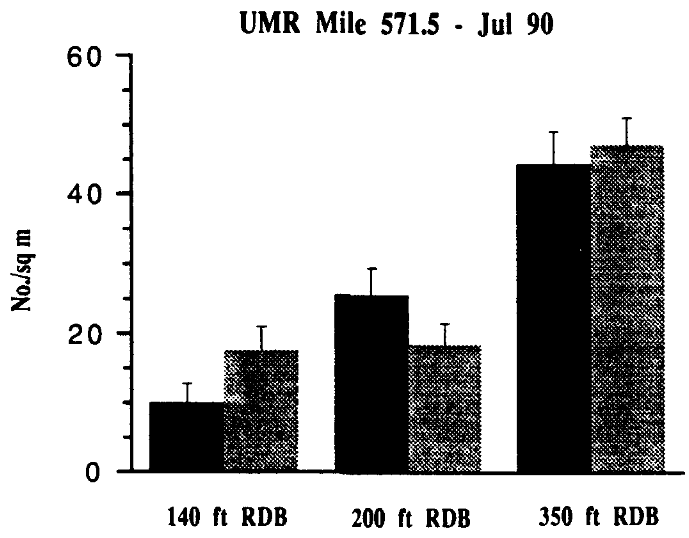


Figure 9. Total density and standard error bars for freshwater mussels at RM 450.4 and 571.5, UMR, 1990.

Table 5

Summary Statistics for Unionids (Average Density and Standard Error, SE) Collected in 0.25 m^2 Quadrats at RM 571.5R, Pool 12, UMR, 1990

Subsite	Distance to Shore, (ft)	Density, avg	SE
1	140	10.0	2.1
2	140	17.6	3.4
Total	140	13.8^{C}	2.1
1	200	25.6	3.9
2	200	18.4	3.2
Total	200	22.0^{B}	2.6
1	350	44.4	4.8
2	350	47.2	4.0
Total	350	45.8^{A}	3.1

Analysis of Variance:

	F*	PR>F**
Among sites	39.78	0.0001

Note: Total density values (all subsites combined) with dissimilar superscript values are not significantly different at the 0.05 level.
* Value from analysis of variance
** Probability of a greater F value

35. Species area curves were also constructed for the quantitative collections at RM 450.4 and RM 571.5 (Figures 12 and 13). At the nearshore site at RM 450.4, the majority of the species were found after 400 individuals were collected. At the farshore site slightly more than 400 individuals were collected, and the curve did not level off as clearly as it did at the nearshore site. The three curves for the quantitative samples at RM 571.5 illustrate that more species might have been found with more intensive sampling. However, considering that L. higginsi (five individuals) as well as other uncommon species were found, it is likely that the majority of the assemblage had been collected with this degree of effort.

36. Five L. higginsi, listed as endangered by the USFWS (1987), were collected using qualitative methods in Pool 12. None were collected in

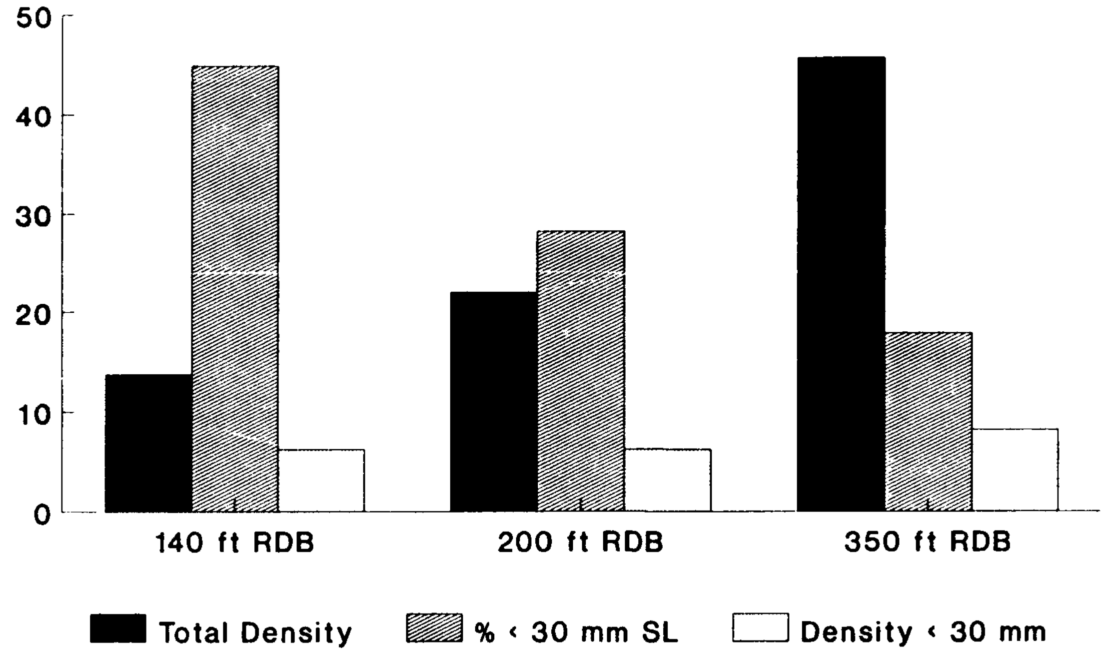


Figure 10. Total density (individuals/sq m), percentage of individuals less than 30 mm total shell length, and density of individuals (1 sq m) less than 30 mm in total shell length at three distances from shore, RM 571.5, UMR, 1990.

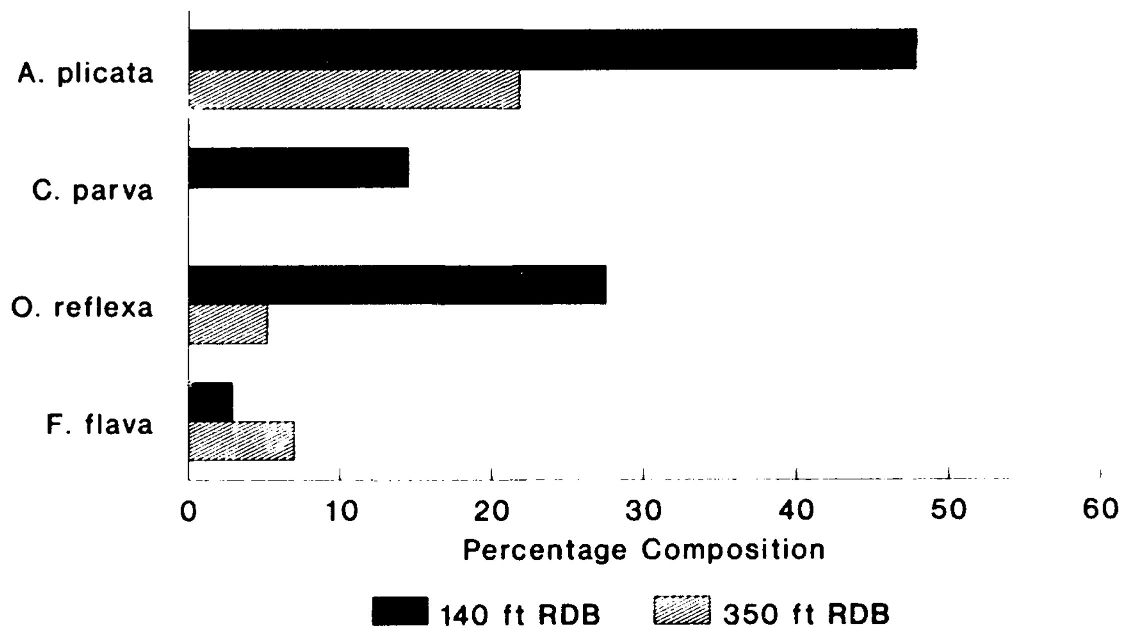
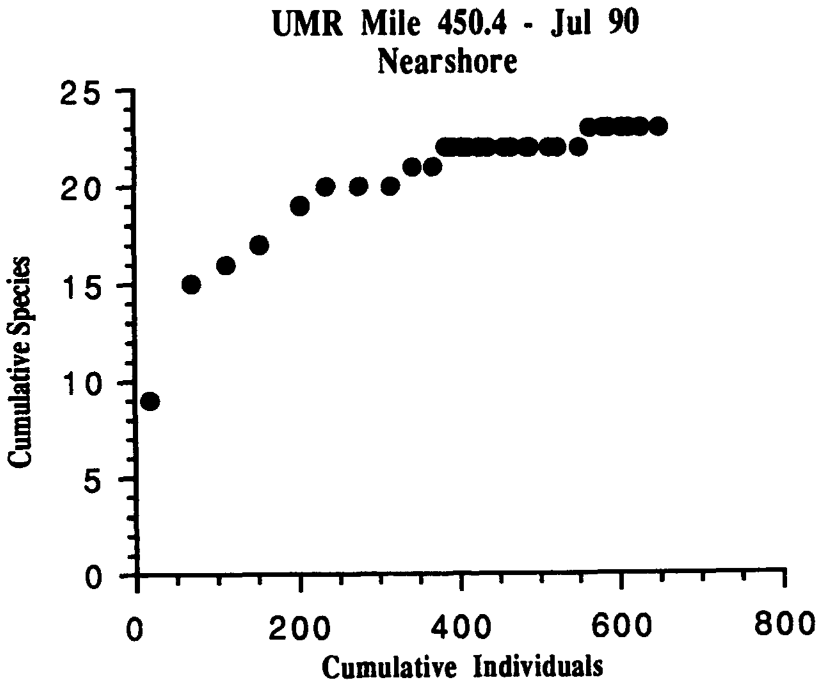


Figure 11. Relative abundance of common-to-abundant mussels at near and farshore sites at RM 571.5 based on quantitative sampling techniques



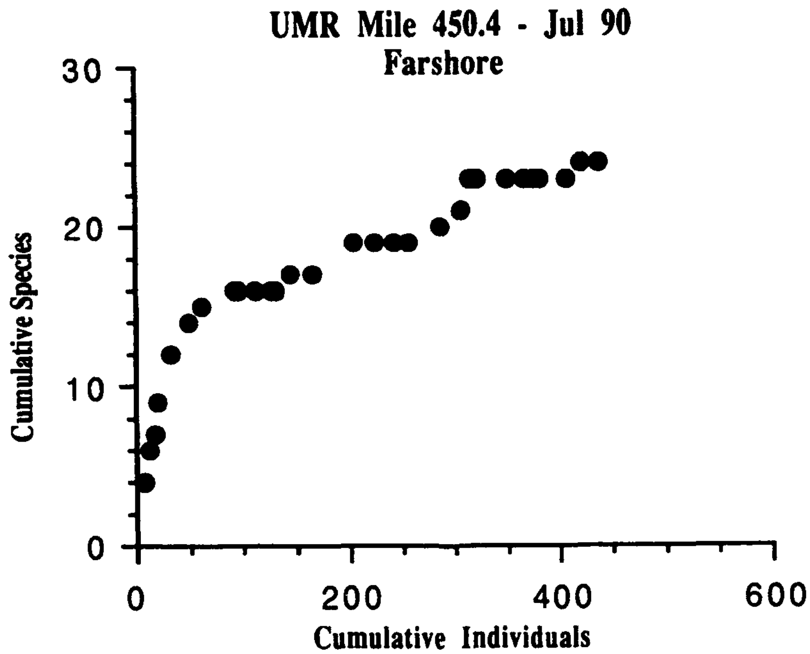


Figure 12. Cumulative species versus cumulative individuals based on qualitative sampling for freshwater mussels at near and farshore sites at RM 450.4, UMR, 1990.

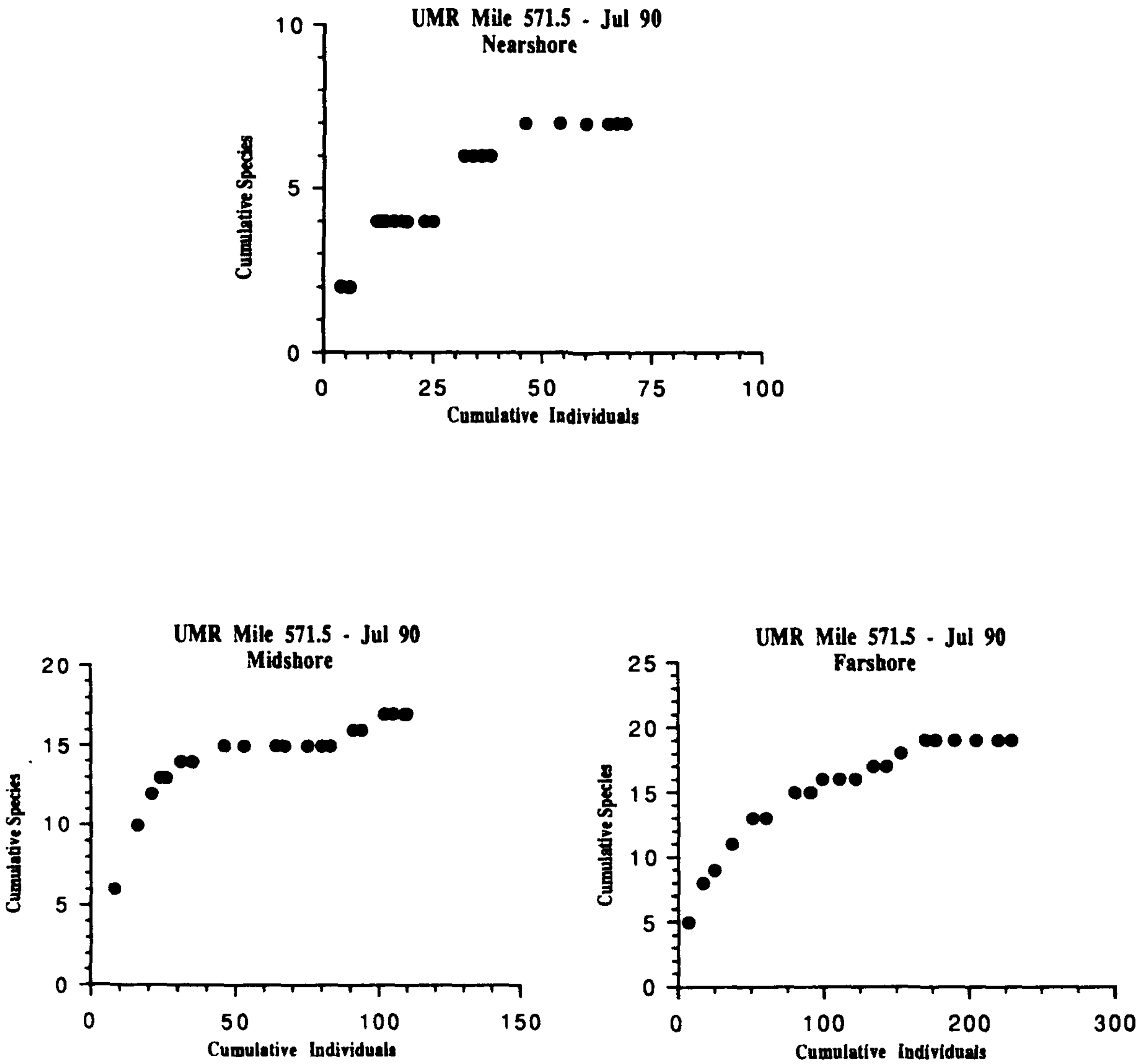


Figure 13. Cumulative species versus cumulative individuals based on qualitative sampling for freshwater mussels at near, middle, and farshore sites at RM 571.5, UMR, 1990.

Pool 17, although this species was collected at this bed in 1989 (Miller et al. 1990). Lampsilis higginsi comprised 0.97 percent of the collection at RM 571.5 (Table A5). At RM 571.5 eight molluscan species were less common than L. higginsi (Table A3). Table 6 includes a summary of L. higginsi collected in the past 3 years of these studies.

Condition Analysis

37. An analysis of mussel condition requires determining relationships between shell length (SL), the components of shell dry mass (SDM), and tissue dry mass (TDM). The relationship of SL to SDM and TDM can be species-specific and is sometimes distinctive between populations within a species. Shell mass is nonliving material that is not removed until death, although small quantities can be lost by erosive action of high water flow. Tissue

Table 6

Numbers of Lampsilis higginsi Taken in Qualitative and Quantitative Samples in the UMR, 1988-90

	Quantitative			Qualitative		
	Total	L. higginsi		Total	L. higginsi	
Location	Mussels	Total	%	Mussels	Total	%
Pool 17 (RM 450)						
1988	--	--	--	567	1	0.18
1990	--	--	--	--	--	--
Pool 12 (RM 570)						
1989	--	--	--	98	0	0
1990	408	5	1.22	518	5	0.98
Pool 14 (RM 505)						
1988	253	1	0.40	734	8	1.09
1989	1,131	1	0.09	961	5	0.52
Pool 10 (RM 635)						
1988	845	2	0.24	699	12	1.72
1989	1,616	11	0.68	212	0	0

Note: More precise river miles can not be given since there were variations of approximately 0.1-0.4 miles among years.
The dashes indicate that samples were not collected from that site during that year.

mass represents most of the energy (caloric) component of the standing crop biomass of standard ecological studies. The relationship between shell mass and tissue provides an index of the relative robustness of the tissue and shell for a species population. These relationships are important baseline indicators of condition. The ratio of tissue mass to shell length can vary seasonally or with respect to reproductive condition. The ratio of shell mass to shell length can be affected by calcium content of the water or by erosion which usually is more noticeable in older animals. These condition indices can reflect the overall health of a population since they are usually affected by environmental characteristics.

38. Baseline data on physical condition (ratios of tissue dry mass to shell length and shell mass) were obtained for a size series of freshwater mussels collected at RM 504.8 (Figures 14-21). If future commercial vessel movement causes substrate scour, then shells could be eroded and relationships between shell length and shell mass could differ from baseline conditions. If increased frequency of turbulence at the substrate-water interface negatively affects respiration and metabolism of individual mussels, then relationships between shell mass (or length) and tissue mass could be negatively affected (see Payne and Miller 1987).

39. As these data illustrate, there were no substantial condition differences with respect to distance from shore (see Figures 16-21). Although condition indices can be affected by water velocity and substrate, at this mussel bed intersite differences were relatively minor. However, these baseline condition data will also be used for future comparisons to assess environmental effects of commercial navigation traffic.

Demographic Analysis

40. Data from quantitative samples collected in 1990 were used for analyses of population demographics. Nearshore and farshore sites in Pools 17 and 14 were combined to increase the number of individuals available and because differences in size demography were not evident between these sites. Only species with suitably high numbers (i.e. at least 25 individuals) were evaluated.

Amblema plicata

41. Both populations (RM 450.4 and RM 571.5) included a wide and nearly complete size range of individuals (Figure C1 and C2, Appendix C). At

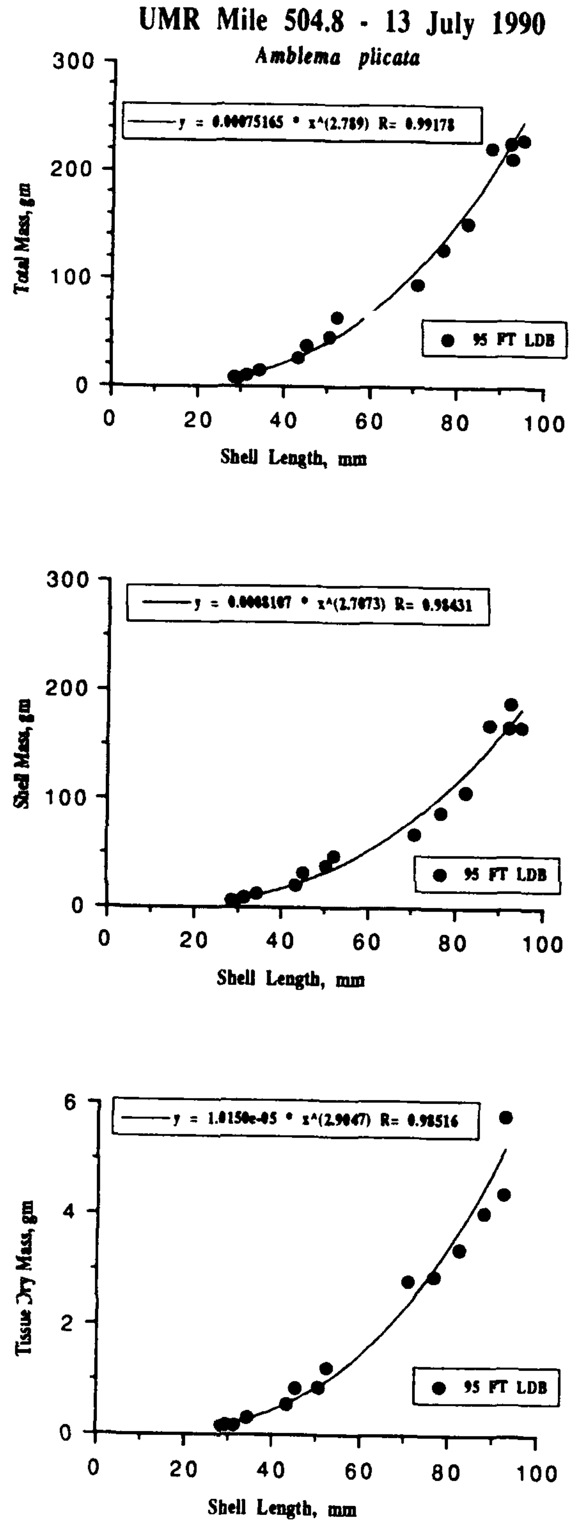


Figure 14. Condition relationships for A. plicata, UMR, July 1990

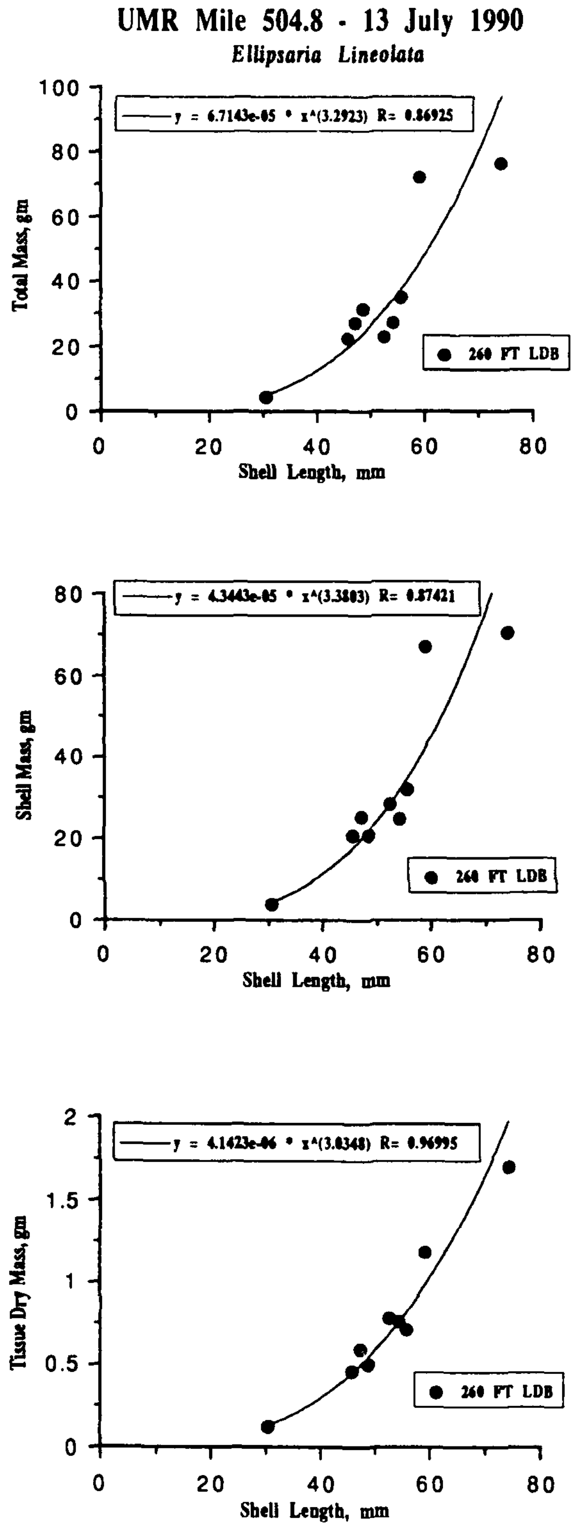


Figure 15. Condition relationships for E. lineolata, UMR, July 1990

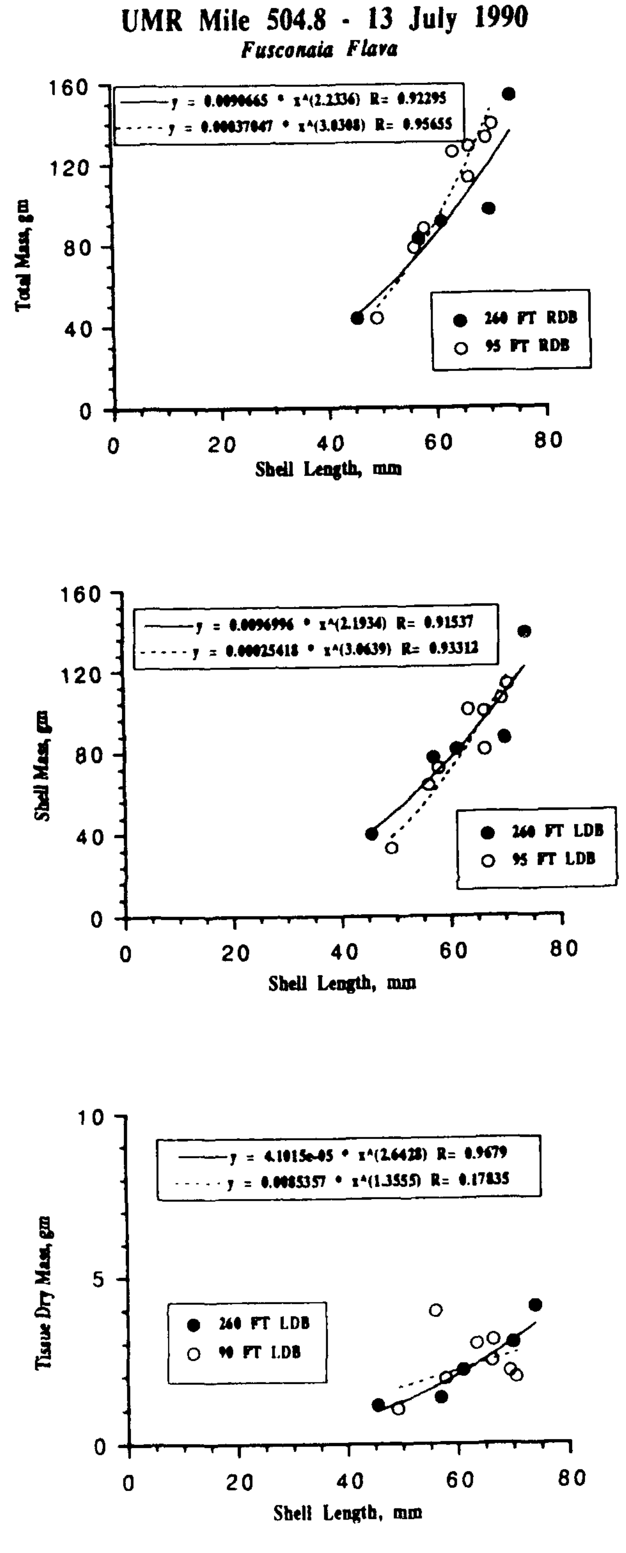


Figure 16. Condition relationships for F. flava, UMR, July 1990

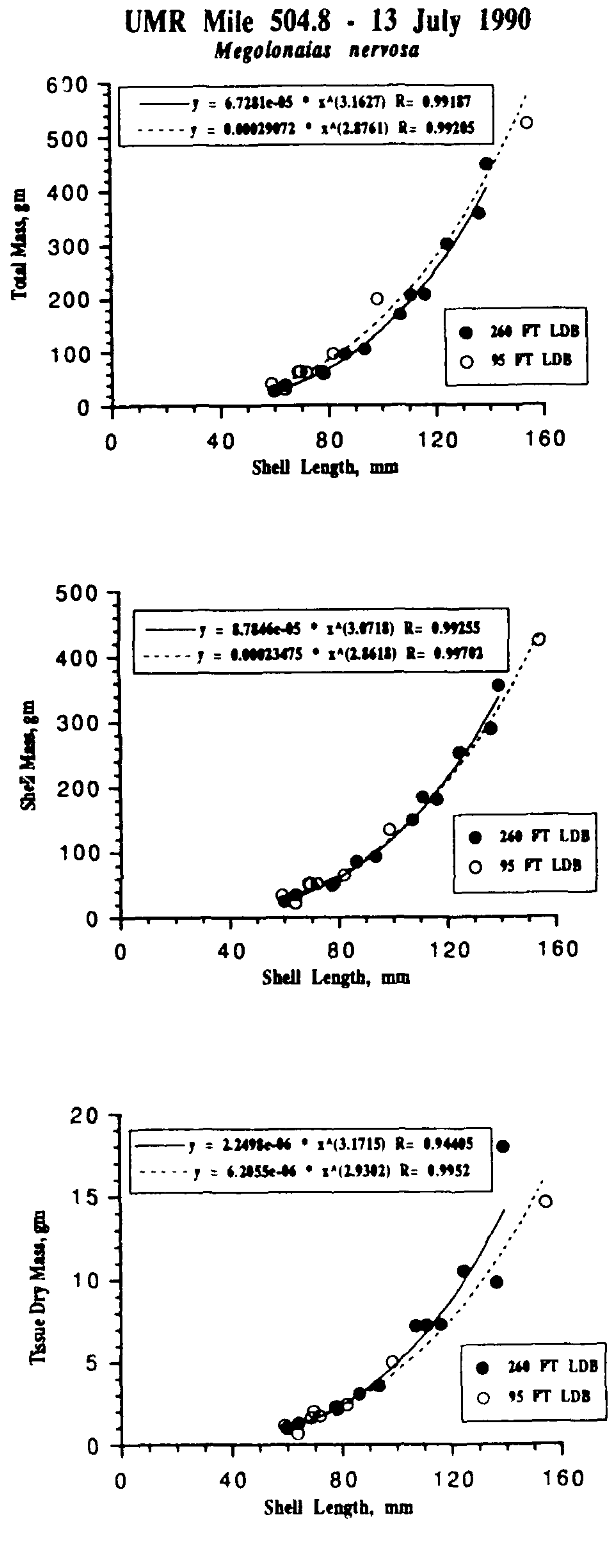


Figure 17. Condition relationships for M. nervosa, UMR, July 1990

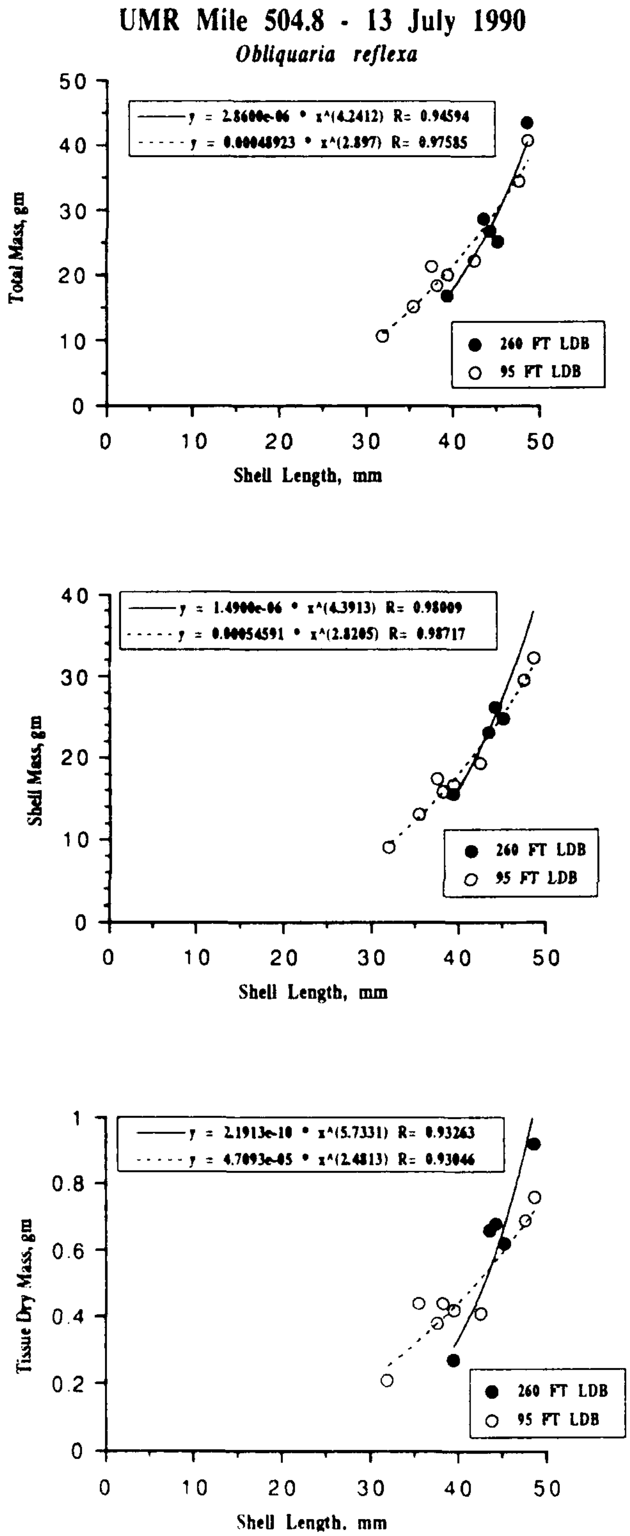


Figure 18. Condition relationships for O. reflexa, UMR, July 1990

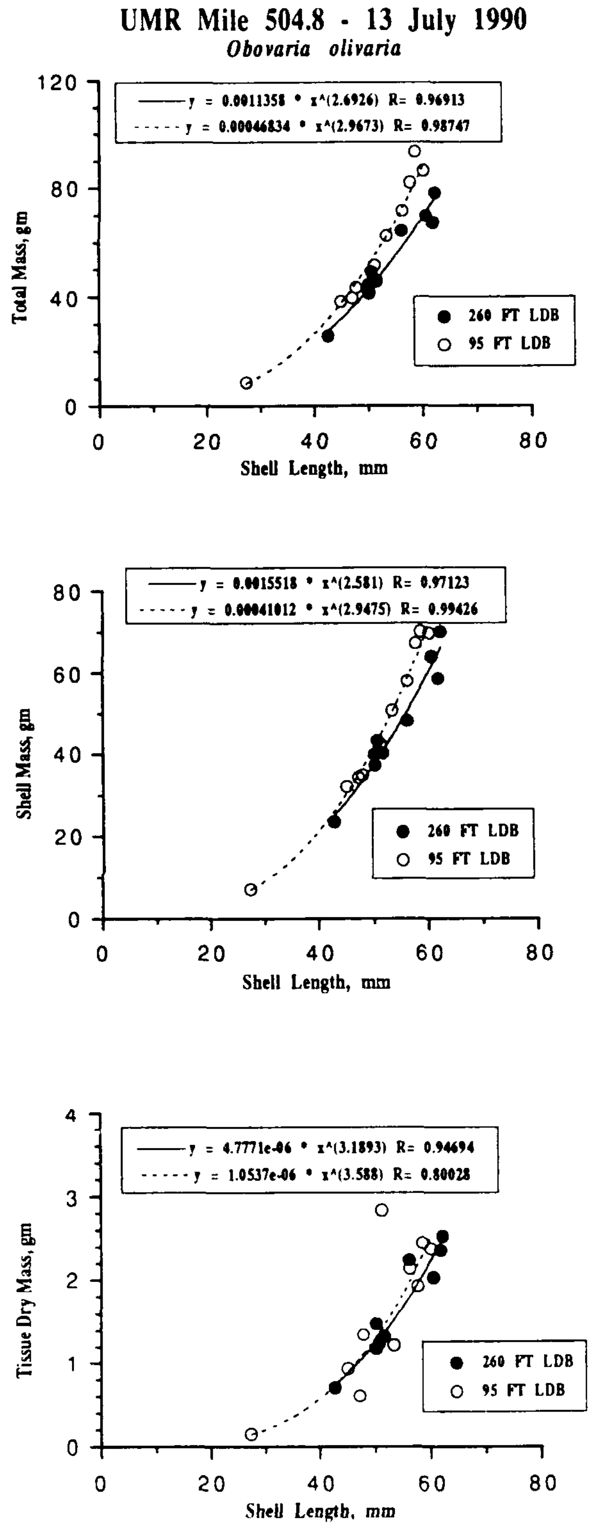


Figure 19. Condition relationships for O. olivaria, UMR, July 1990

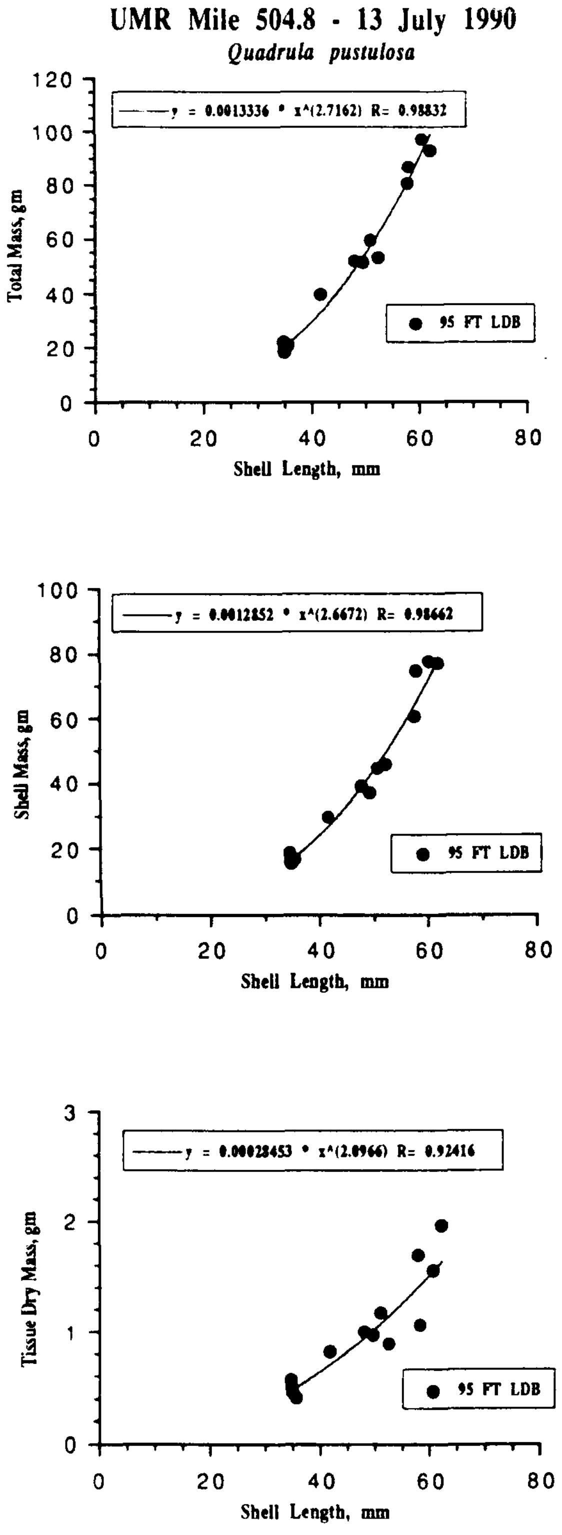


Figure 20. Condition relationships for Q. pustulosa, UMR, July 1990

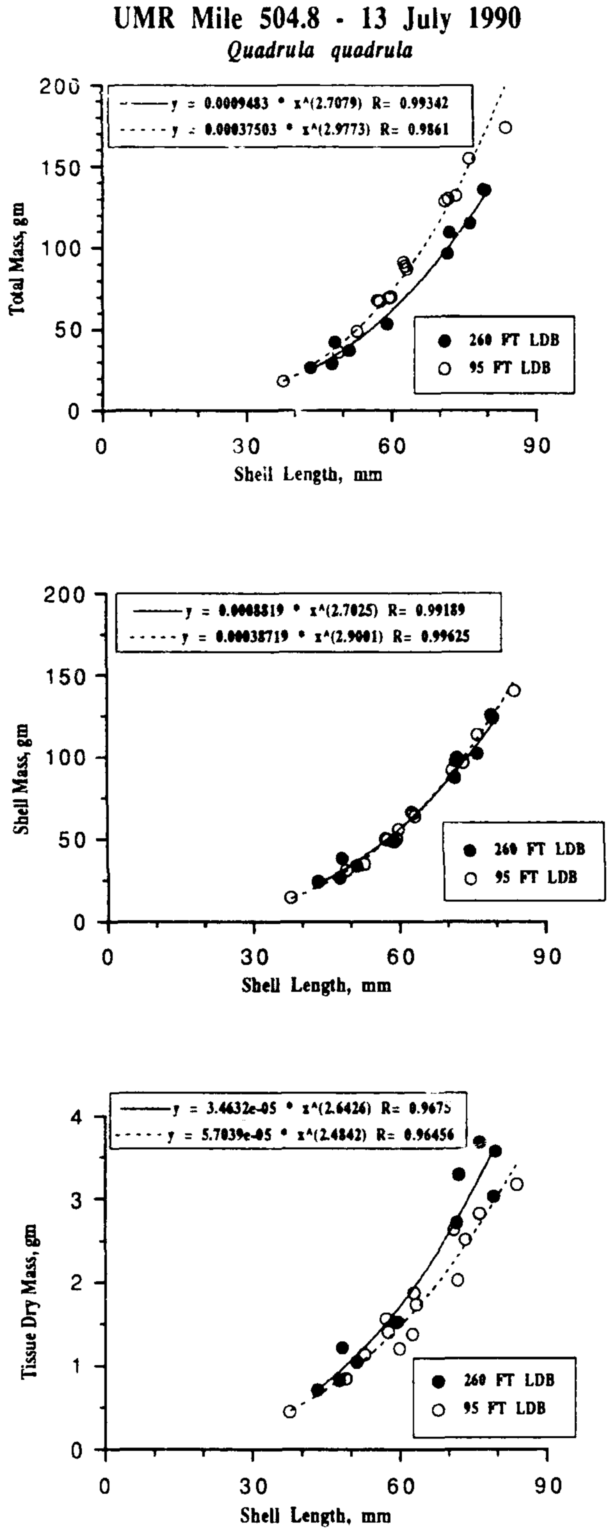


Figure 21. Condition relationships for Q. quadrula, UMR, July 1990

RM 450.4, a sample of 243 individuals spanned 15 to 103 mm. At RM 571.5, the smallest individual was 15 mm and the largest was 105 mm. However, at RM 571.5, there was relatively equal abundance of individuals throughout the entire size range, whereas at RM 450.4, the population was dominated by individuals of moderately large size. Fifty-one percent of A. plicata at RM 450.4 were between 72 and 88 mm in SL.

Ellipsaria lineolata

42. This species was collected in sufficient numbers for detailed analysis of size demography only at RM 450.4 (Figure C3). The population was dominated by mussels ranging in SL from 38 to 56 mm (64 percent of all individuals were within this range), although a total range of 16 to 90 mm was represented among individuals obtained from quantitative samples. As for the A. plicata population, it appears that there was substantial interannual variation in recruitment strength that lead to subsequent intercohort variation in relative abundance.

Leptodea fragilis

43. Individuals of this species ranged from 24 to 102 mm in SL at RM 450.4 (Figure C4) but were not obtained in sufficient numbers for analysis of size demography at RM 450.4. All but 4 of 77 individuals obtained at RM 571.5 were between 38 and 96 mm long, and individual cohorts could not be discerned.

Megalonaias nervosa

44. The size demography of populations of this species were similar at RM 450.4 and 571.5 (Figures C5 and C6, respectively). At RM 450.4, all but 2 of 48 individuals fell within the range of 38 to 106 mm SL; only 2 large individuals (155 and 163 mm SL) occurred in the sample. Similarly at RM 571.5, all but 4 of 31 individuals were within the range of 54 to 118 mm SL; only 1 individual greater than 150 mm SL was obtained. Recruitment of this species appears sufficiently high to maintain populations, but the paucity of truly large M. nervosa, a common situation throughout the UMR, may indicate that commercial preference for this harvested species keeps the relative abundance of large adults at a low level.

Obliquaria reflexa

45. The populations of this species differed at RM 450.4 and 571.5 (Figures C7 and C8, respectively). A single cohort of intermediate size (mostly 34 to 44 mm SL) was heavily dominant at RM 450.4, but two approximately coequally abundant cohorts (centered at 24 to 28 mm SL and 34 to 38 mm

SL) appeared to dominate the population and RM 571.5. These two cohorts probably represent consecutive year classes, and only the older of the two appears to have been abundant at RM 450.4.

Quadrula pustulosa

46. This species was obtained in sufficient numbers for demographic analysis only at RM 450.4 (Figure C9). The population at that location was not clearly dominated by any single cohort. Instead, individuals spanning the range of 22 to 62 mm SL were all abundant, although mussels measuring 38 to 62 mm were most abundant. The lack of individuals less than 22 mm indicates that the most recent year of substantial recruitment was probably 1988.

Quadrula quadrula

47. This species was collected in barely sufficient numbers for demographic analyses at both RM 450.4 and RM 571.5 (Figures C10 and C11, respectively). The two populations were similar in that individuals spanned from approximately 22 to 90 mm SL, and no single cohort dominated.

Truncilla donaciformis

48. This species was collected in abundance only at RM 450.4 (Figure C12). At this location, the population consisted of individuals ranging from 10 to 30 mm SL. Cohort structure could not be discerned for this population of a small and short-lived species.

Truncilla truncata

49. This species was found in abundance at RM 450.4 (Figure C13) but not at RM 571.5. Individual cohorts were not clear in the size demography of this relatively small and short-lived species; most individuals measured from 26 to 42 mm SL.

Comparison of 1988 and 1990 Demography, RM 450.4

Amblema plicata

50. In July 1988, 47 of 97 (48 percent) A. plicata obtained had SL between 68 and 82 mm at the site in Pool 17 (Figure C14). This abundant group of moderately large mussels remained the dominant aspect of the population's size demography in July 1990, when 124 of 243 (51 percent) individuals collected were between 72 and 88 mm. The average SL of these moderately large mussels was 74.7 mm in 1988 and 80.1 mm in 1990, indicating an increase in length of 5.4 mm over 2 years. This rate of increase translates into an annual increment of approximately 2.7 mm, and this increment is in concordance

with the spacing (difficult to clearly discern and interpret) of apparent annuli near the outer shell margin of moderately large A. plicata.

51. In addition to allowing estimation of annual growth, this 1988 to 1990 comparison of population size demography provides evidence that mortality of these moderately large mussels was negligible over the 2-year interval between samples. This assumption is based not only on the similarity of this size group's relative abundance in 1988 (48 percent) and 1990 (51 percent) but also is supported by the low abundance both of very large, old mussels and very small, young mussels in the populations. High abundance of very large, old individuals prone to high natural mortality and high abundance of very small, young mussels representing infusion of new recruits to the population are both factors that affect the expected stability of relative abundance estimates of intermediate size and age classes. These factors were probably not of major importance from 1988 to 1990, although measurable recent recruitment was indicated by the presence of a few small individuals in 1990. A cohort of recent recruits ranging in SL from 14 to 22 mm long and comprising 5 percent of the population was apparent in 1990. It is likely that this cohort represents 1988 recruitment, although no A. plicata less than 20 mm in SL were obtained in 1988. The 1988 year class may not have yet settled by July 25, the date of sampling in 1988, and would have been too small to have been retained on the screens used to sieve sediments.

Ellipsaria lineolata

52. In July 1988, 32 of 52 (62 percent) individuals obtained from this population were between 24 and 32 mm long at the site in Pool 17 (Figure C15). In July 1990 this abundant group of mussels ranged from 38 to 56 mm long and comprised 64 percent (86 of 135 individuals) of the population (Figure C3). The sustained relative abundance of this cohort from 1988 to 1990 indicated negligible mortality during growth from small to intermediate size and age. Average length of this cohort increased by 18.4 mm during the 2-year life span, from 28.3 in 1988 to 46.7 in 1990. Recruitment appears to have been negligible since the year (probably 1986) in which this dominant cohort settled.

PART IV: PHYSICAL EFFECTS OF COMMERCIAL VESSEL PASSAGE

Changes in Water Velocity

Background

53. Water velocity was measured at two to four locations (on a transect running from near to farshore) for 24 vessel passages in July 1990 (Table 7). Data were collected at RM 450.4 (Pool 14) and RM 571.5 (Pool 12). Sensors were placed at distances ranging from 70 to 460 ft from the bank. Water velocity data were collected at sites that supported diverse mussel assemblages; quantitative data on mussels were obtained 75 and 120 ft from the RDB at RM 450.4, and 140, 200, and 350 ft from the RDB at RM 571.5 (Table 2). A summary of information on each vessel passage appears in Table 7. Summary statistics for each passage appear in Appendix D, and individual plots of water velocity appear in Appendix E. Each data collection event was labeled a test; these are numbered consecutively, Table D1, sheets 1 through 41, and Figures E1 through E69.

54. The first set of data, collected on 9 July 1990 (Test 1), was obtained under ambient conditions when no vessels were present (Figures E1-E3). Tests are arranged as follows: the first set of figures contains individual X-Y plots, the second set contains the net or combined velocity, and the final set contains the compass direction. In the majority of the cases four sensors were deployed for each test. However, for Tests 6-11 (11 July 90) only two sensors were deployed, and for Test 12 (15 July 90) only three sensors were deployed. Only two sensors were deployed on 11 July because of the need to concentrate on biological sampling. Only three sensors were in place during Test 12; the fourth had not been deployed when the vessel passed the site.

Little or no measurable effect of vessel passage

55. Passage of four vessels caused no discernible velocity changes. These were Tests 2, 4, 13, and 14, depicted in Appendix E. Examination of these figures reveals that vessel passage (noted by an upward or downward pointing arrow along the X axis) did not noticeably affect water velocity. For example, summary statistics for Test 2 illustrate the minor effect of vessel passage; the range in individual velocity components (X, Y) and

Table 7

Physical Information Pertaining to Vessel Passage, UMR, July 1990

(All Distances are in Feet)

Date (July)	Event No.	Test No.	River Mile	Start	Passes	Front of tow Passes	End of tow Passes	End of tug Stop	Main File	Front Passes	End Passes	End Passes	No Barges	Total Length	Sec to pass	ft/sec	mi/hr
9	1	1	448.7r	170705	ND	ND	ND	172440	901901	ND	ND	ND	ND	ND	ND	ND	ND
9	-	2	448.7r	173749	174041	174054	174100	174620	901902	173	186	192	1	185	13	14.23	9.70
10	1	3	450.4r	113832	114414	114620	114638	115732	901911	343	469	487	5	925	126	7.34	5.01
10	2	4	450.4r	133341	133542	133621	ND	134310	901912	62	161	ND	ND	ND	99	0.00	0.00
10	3	5	450.4r	153110	153349	153532	153551	154310	901913	160	263	282	4	740	103	7.18	4.90
11	1	6	450.4r	105310	105551	105707	ND	110559	901921	162	238	ND	5	925	76	12.17	8.30
11	2	7	450.4r	111200	111729	111945	112004	112730	901922	330	466	485	5	925	136	6.80	4.64
11	3	8	450.4r	122250	122841	123031	123045	123725	901923	352	462	476	3	555	110	5.05	3.44
11	4	9	450.4r	124355	124631	124808	124826	125059	901924	157	254	272	5	925	97	9.54	6.50
11	5	10	450.4r	151820	152039	152048	152338	152359	901925	140	149	ND	ND	ND	9	0.00	0.00
11	6	11	450.4r	165530	165836	165956	170016	170530	901926	187	267	286	4	740	80	9.25	6.31
15	1	12	571.5r	110900	111344	111445	111500	112358	901961	285	346	361	3	555	61	9.10	6.20
15	2	13	571.5r	115200	115349	115525	115543	115859	901962	110	206	224	5	925	96	9.64	6.57
15	3	14	571.5r	115900	120334	120350	120400	121459	901963	275	291	301	1	185	16	11.56	7.88
15	4	15	571.5r	142300	142717	142848	142901	143954	901964	268	349	362	5	925	81	11.42	7.79
15	5	16	571.5r	180720	180722	180816	180826	181440	901965	3	57	67	4	740	54	13.70	9.34
15	6	17	571.5r	180720	180832	181009	181021	181440	901965	73	170	182	5	925	97	9.54	6.50
16	1	18	571.5r	94310	94420	94515	94528	95100	901971	71	126	139	3	555	55	10.09	6.88
16	2	19	571.5r	101920	102435	102626	102637	103159	901972	316	427	438	5	925	111	8.33	5.68
16	3	20	571.5r	151050	152236	152458	152522	153400	901973	706	849	872	5	925	143	6.47	4.41
16	4	21	571.5r	163110	163533	163544	ND	163810	901974	264	275	ND	0	0	11	0.00	0.00
17	1	22	571.5r	ND	111453	111538	111554	112635	901981	294	339	355	4	740	45	16.44	11.21
17	2	23	571.5r	124314	124805	124926	124940	130134	901982	286	367	381	5	925	81	11.42	7.79
17	3	24	571.5r	165420	170051	170316	170335	171100	901983	392	537	556	5	925	45	6.38	4.35

(Continued)

Note: ND refers to no data

Table 7 (Concluded)

Test No	Sensor #1 Dist.	Sensor #1 Depth	Sensor #2 Dist.	Sensor #2 Depth	Sensor #3 Dist.	Sensor #3 Depth	Sensor #4 Dist.	Sensor #4 Depth	Vessel Name	Configuration (len x wid)	Total Barges	Vessel Condition	Vessel Distance	Vessel Direction
1	90	9	110	13	190	19	320	22	(Ambient Conditions)	ND	ND	ND	ND	ND
2	90	9	110	13	190	19	320	22	C. W. Rushing	1	1	Unloaded	500	Down
3	70	16	130	25	260	22	375	21	Sammuel B. Richmond	5 x 2	11	Loaded	480	Up
4	70	16	130	25	260	22	375	21	Mississippi Queen	ND	ND	ND	375	Up
5	70	16	130	25	260	22	375	21	Edward J. Hancock	4 x 3	12	Unloaded	450	Up
6	125	24	375	25	ND	ND	ND	ND	Cooperative Vanguar	5 x 3	15	ND	600	Down
7	125	24	375	25	ND	ND	ND	ND	Jack Bullard	5 x 2	10	Partial	600	Up
8	125	24	375	25	ND	ND	ND	ND	Cindy L. Erikson	3 x 3	10	Unloaded	475	Up
9	125	24	375	25	ND	ND	ND	ND	Mary L.	5 x 3	15	Loaded	500	Down
10	125	24	375	25	ND	ND	ND	ND	Evylen C.	Tug	ND	ND	700	Up
11	125	24	375	25	ND	ND	ND	ND	Western	4 x 3	12	Loaded	750	Down
12	110	24	140	28	220	32	300	33	Phyllis	3 x 3	9	Loaded	450	Down
13	110	24	140	28	220	32	300	33	Anne Holly	5 x 3	15	Unloaded	500	Up
14	110	24	140	28	220	32	300	33	Hoosier State	1 x 3	3	Unloaded	450	Up
15	110	24	140	28	220	32	300	33	T.S. Kunsman	5 x 3	15	Loaded	480	Down
16	110	24	140	28	220	32	300	33	Hoosier State	4 x 3	12	Loaded	500	Down
17	110	24	140	28	220	32	300	33	Eugen	5 x 3	15	Loaded	400	Down
18	105	6	240	20	305	32	410	33	Dell Butcher	3 x 3	9	Partial	510	Down
19	105	6	240	20	305	32	410	33	Lawson and Lawson	5 x 3	15	Loaded	500	Down
20	105	6	240	20	305	32	410	33	Milton V. Roth	5 x 3	15	Loaded	450	Up
21	105	6	240	20	305	32	410	33	Mississippi Belle	ND	ND	ND	650	Up
22	85	9	210	21	305	29	460	34	Margaret M. Igent	4 x 3	12	Unloaded	540	Up
23	85	9	210	21	305	29	460	34	Cooperative Ambassa	5 x 3	15	Loaded	450	Down
24	85	9	210	21	305	29	460	34	Jana Southern	5 x 3	16	Unloaded	500	Up

Note:

Sensor	Model	File	Logger
1	942	T1	A
2	946	T2	A
3	939	T3	B
4	940	T4	B

Nearshore = 1; Farshore = 4, etc. for 9-17 July and 21 July, 1990 combined velocity is always slightly greater during vessel passage than before passage (Table D1, sheets 2 and 3).

Minor effect of vessel passage

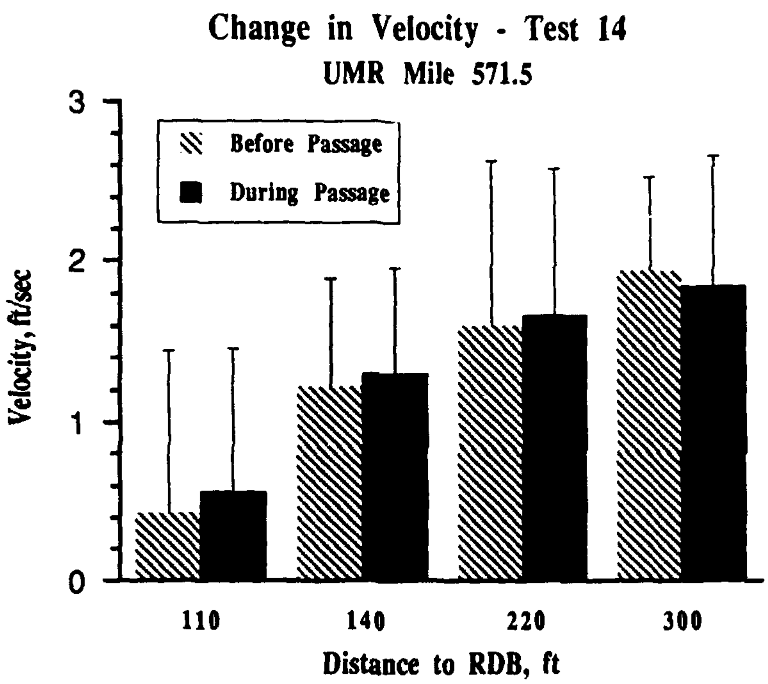
56. Eleven vessel passages caused only minor changes to water velocity that was discernible at one or more sensors. Minor velocity changes were noted for Tests 3, 5, 6, 7, 8, 9, 10, 11, 12, 15, and 21. The slight but noticeable decrease in combined velocity in Tests 6, 8, and 9 was caused by vessel displacement and not propeller wash. These abrupt shifts in velocity are notable whether a vessel is passing upriver or downriver; they are caused by the hull displacing large quantities of water. The decrease in velocity parallel to flow (Y component) and slight increase at right angles to flow (X component) following downbound passage (Test 15) was most noticeable at a distance of 300 ft from the RDB (Figure E43).

Moderate to high effects of vessel passage

57. Moderate to high water velocity changes were noted for eight passages. Tests 16 and 17 (which took place almost simultaneously, Figure E17), as well as Tests 18, 19, 20, 22, 23, and 24, illustrate comparatively high velocity changes resulting from vessel passage. However, in none of these tests did velocity exceed 2 ft/sec even for a short period of time. For Test 20, at a distance of 105 ft from the RDB, a comparatively abrupt velocity change was noted (Figure E55). Before the vessel passed, mean and range in velocity parallel to flow (the Y component, see Table D1, Test 20) were 0.279 and 0.112 ft/sec, respectively. Immediately after passage, the mean and range in velocity were 0.458 and 0.413 ft/sec, respectively. Before vessel passage, the maximum water velocity (for a 200-sec unit of time) was 0.345 ft/sec. During passage, the maximum velocity approximately doubled to a maximum of 0.657 ft/sec.

Concluding comments

58. Changes in mean velocity parallel to flow (Test 14) as a result of vessel passage is depicted graphically in Figure 22. For this test (upbound), the mean velocity during passage was slightly greater at three of the four sensors. Velocity changes caused by Test 20, (also an upbound vessel) were substantially greater than those depicted for Test 14 (compare Figures E55 through E57 with Figures E40 through E42). Regardless of the magnitude of the event, velocity increases for a 200-sec time increment can be considered minor.



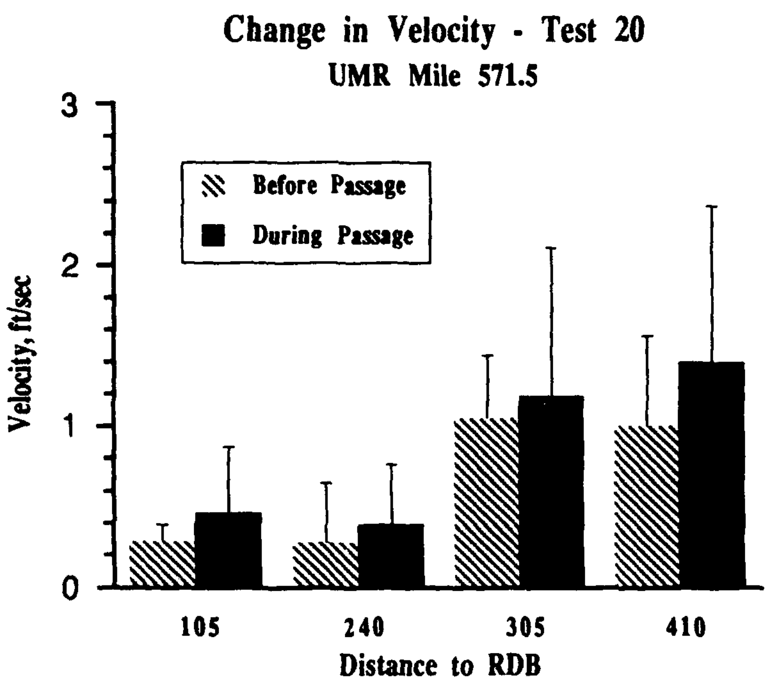


Figure 22. Mean and range in velocity (ft/sec) immediately before and during tests 14 and 20, UMR, July 1990. Velocity readings were taken parallel to flow. See tests 14 and 20 in Appendix E

59. A comparison of summary statistics for the 200-sec increment before and during vessel passage provides a mechanism for assessing the physical effects of upbound versus downbound vessel passage. Maximum and minimum velocity readings for a 200-sec period are influenced by the direction of vessel movement. A summary of changes in minimum and maximum velocity for all 24 events, and all sensors used for each event, appears in Figure 23. Passage of an upbound vessel appeared to have little effect on minimum velocity, however maximum velocity was increased (compare top left with bottom left figures). When a vessel moves upriver, the displacement causes return flow which increases ambient velocity. This increase has no effect on minimum velocity. When a vessel moves downriver, the return flow tends to reverse the current thereby reducing minimum velocity. The return flow from a downbound vessel has little or no effect on maximum velocity (compare top right with bottom right plots of Figure 23).

Changes in Turbidity

60. Water samples were collected immediately before and after commercial vessels passed the collection site for Tests 23 and 24 (Figure 24). For Test 23 ambient turbidity was slightly higher in water collected near the substrate-water interface (close to 40 Jackson Turbidity Units (JTU)) than it was at the surface (approximately 25 JTU). Vessel passage caused a peak in turbidity of approximately 90 JTU; however, turbidity declined after nearly 300 sec at the substrate-water interface to slightly above ambient conditions. Turbidity had returned to ambient conditions after 750 sec had elapsed. A smaller turbidity peak near the substrate-water interface took place during Test 4 (Figure 24). The increase in turbidity occurred immediately before the vessel passed. The comparatively high value caused by the vessel declined to near ambient levels within 2 min of passage.

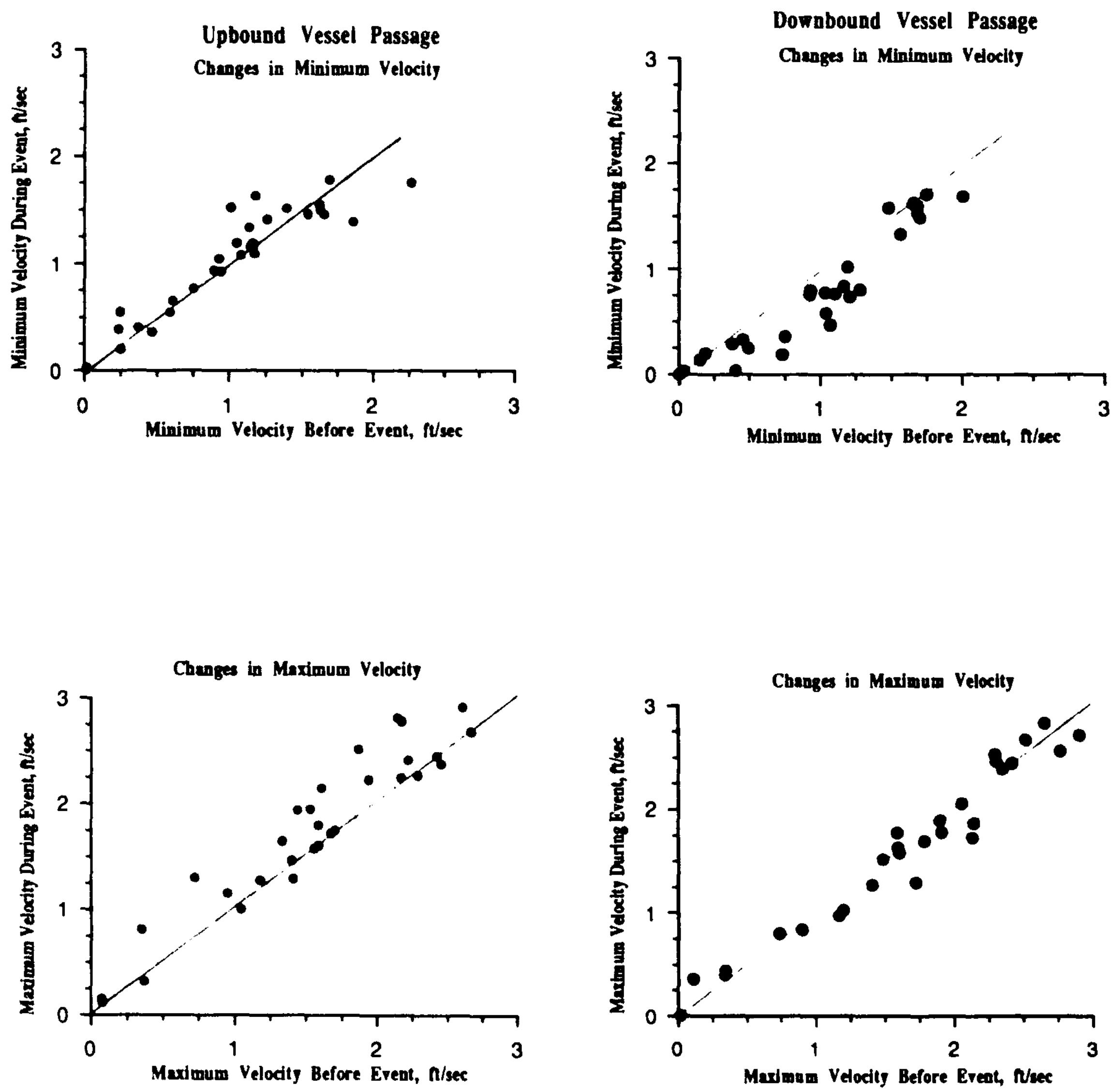
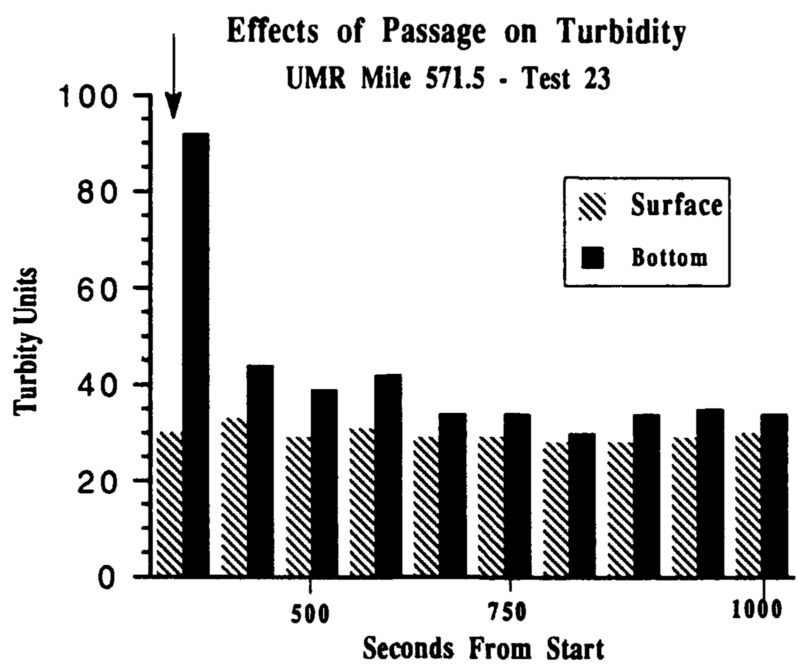


Figure 23. The effects of upbound and downbound vessels on minimum and maximum velocity (see text for details).



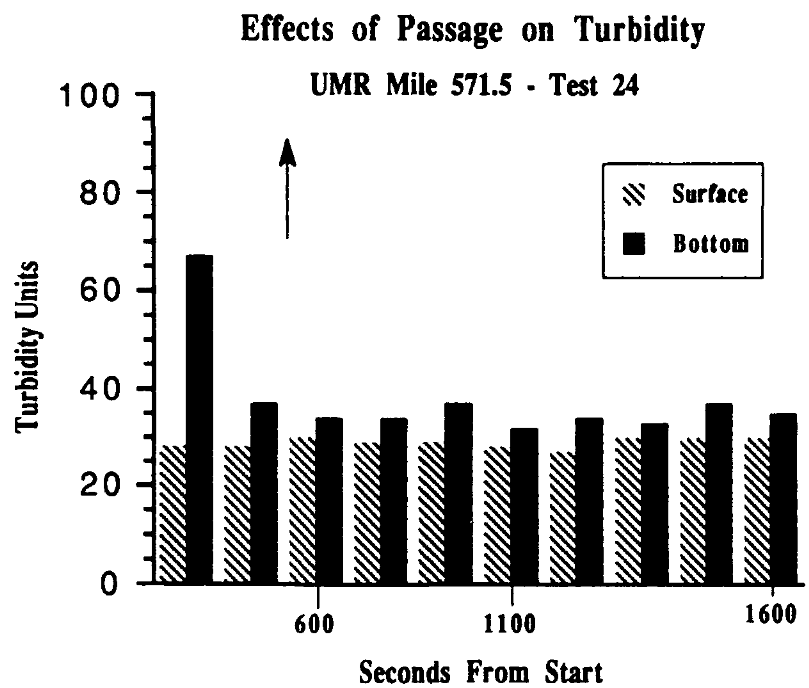


Figure 24. Effects of vessel passage on turbidity in surface and bottom (immediately above the substrate-water interface) for tests 23 and 24, UMR, July 1990.

PART V: DISCUSSION

Background

61. In the United States three projects are responsible for drawing attention to the environmental effects of commercial navigation traffic. These are the Tennessee-Tombigbee Waterway, a connecting link between the Tennessee and Tombigbee Rivers in Alabama and Mississippi; replacement locks and dam in the Mississippi River near Alton, IL; and construction of a new lock in the Ohio River at Gallipolis between Ohio and West Virginia. However, during the last 10 years environmental groups and state conservation agencies appear to be more concerned with effects of vessel movement than potential habitat alteration caused by construction. As a result, much speculation and discussion on this topic has appeared, most in the government or nonrefereed literature (Virginia Polytechnic Institute and State University 1975; Academy of Natural Sciences of Philadelphia 1980; Berger Associates, Ltd. 1980, Sparks et al. 1979; US Army Corps of Engineers 1980; Lubinski et al 1980, 1981; Environmental Science and Engineering 1981, 1988; Kennedy, Harber, and Littlejohn 1982; Rasmussen 1983; Simons et al. 1981, Simons, Ghaboosi, and Chang 1987; Wuebben, Brown, and Zabilansky 1984; and Nielsen, Sheehan, and Orth 1986). Much of this writing was considered speculative by Wright (1982). Regardless, the increased use of inland waterways to transport bulk commodities (Dietz et al. 1983) and the recent articles on impacts of waterway use in Europe (Brookes and Hanbury 1990 and Haendel and Tittizer 1990) suggest that this issue will remain important well into the 21st century.

62. A review of the literature indicates that the pulse of velocity and turbulence is usually considered to be the major detrimental effect of vessel passage. It has been suggested that vessel-induced change in magnitude and direction of flow negatively affects benthic organisms by scouring substrates and resuspending fine-grained sediments. Tolerances of many aquatic organisms to sustained, specific levels of turbulence, water velocity, or suspended solids is known either from laboratory or field studies. Intermittent disturbances caused by vessel movement, pulses of suspended sediments, changes in water velocity, and periods of desiccation, can be simulated in the laboratory. Navigation-related studies have been conducted on fish eggs (Morgan et al. 1976 and Holland 1987), fish larvae (Killgore, Miller, and Conley 1987, Holland 1987, and Payne, Killgore, and Miller 1991), plankton (Stevenson

et al. 1986), and freshwater mussels (Aldridge, Payne, and Miller 1987; Payne and Miller 1987). Results of most studies demonstrated that mortality or physiological stress could be measured under conditions corresponding to high traffic intensity. In the field, discharge, flow patterns, bathymetry, and sediment characteristics have complex influences on vessel-induced disturbances. It is extremely difficult to estimate an organismal response to these intermittent physical effects, and it is even more difficult to accurately predict long-term responses of natural populations to such disturbances. Results of the few navigation-related field studies that have been conducted are characterized by extreme spatial and temporal variability so that clear patterns of navigation effects often cannot be discerned (Sparks, Thomas, and Schaeffer 1980; Bhowmik et al. 1981a, 1981b; Seagle and Zumwalt 1981; Eckblad 1981; Eckblad, Volden, and Weilgart 1984; Environmental Science and Engineering 1981; and Holland 1986). In addition, natural climatic and hydrologic conditions often overwhelm navigation effects (Johnson 1976).

63. Planners and biologists must evaluate the effects of man's activities on populations of species in their natural habitats. Whether as an alternative to or in validation of laboratory simulation, field studies should be used to evaluate the biological effects of tow-induced disturbances. Field studies should provide quantitative data on biotic parameters such as density, relative species abundance, community composition, population demography, and rate of growth. Adequate baseline data should be established, and then additional studies can be used to determine whether commercial navigation causes measurable change. Since commercial traffic affects an entire waterway, planners and conservation groups frequently desire a "system-wide" quantification of environmental impacts. It is more practical to identify and study specific sites with special biological value that are among the most likely to be affected by commercial traffic. Results can then be extrapolated to similar sensitive sites.

64. Freshwater mussels dominate the benthic biomass in most large rivers in the United States (Fuller 1974). Their sedentary lifestyle and reliance on suspended particulate organic matter as food makes them particularly susceptible to turbulence, sedimentation, and fluctuating water levels. Sparks (1975), Sparks et al. (1979), and Lubinski et al. (1981) suggested that decline of freshwater mussels in navigation channels could be caused by commercial traffic. Assumptions were based largely on the knowledge that mussels require stable gravel shoals free of sedimentation. Because they are

longlived and relatively nonmotile, regular quantitative assessments of freshwater mussel populations and communities provide an index of habitat quality. This, in conjunction with their ecological and commercial value and the protected status of the endangered species, makes them ideal monitoring tools.

65. Pygott et al, cited by Brookes and Hanbury (1990), studied fish community structure in four British canals where traffic events ranged from 500 to 10,000 movements per year. Heavily trafficked waterways with high turbidity had the lowest fish species diversity. Murphy and Eaton (1983) reported that low traffic levels (less that 2,000 passages per year) had little effect on abundance and composition of aquatic plant communities. When the number of events exceeded 2,000 per year, the plant communities were negatively affected by water turbulence, turbidity, and suspended sediments. Results of heavily trafficked waterways in Europe (Murphy and Eaton 1983; Brookes and Hanbury 1990) and laboratory experiments by Payne and Miller (1987) suggest that extremely high traffic intensities would be needed to affect certain aquatic organisms.

66. Conservation agencies in the US Federal and State Governments have expressed concern over the environmental effects of commercial vessel movement. This has resulted in the publication of many reports, some speculative and without substantial data (for more detail, see Wright 1982). Part of the problem is the extreme difficulty and expense of conducting field studies on traffic effects. Many species of freshwater mussels and fishes live 20 or more years. At a minimum, definitive cause-and-effect studies should span a sizable segment of their life cycle.

67. Although laboratory experiments provide insight into possible impacts of physical stress to natural populations, definitive empirical data can only be obtained by long-term field studies. Predictions on impacts should not be based on results of a single laboratory experiment or field observation. Key biotic parameters should be regularly monitored just as data are assembled on river discharge, precipitation, or air temperature.

Summary

68. The second year of detailed studies on molluscs and physical changes associated with vessel passage has been completed in the UMR. Four more years of baseline data will be collected at the sites identified in the first phase of this work. Studies have demonstrated that *L. higginsi*

populations (at about 0.5 percent of the assemblage) are stable at sites in Pools 12, 14, and 10. Relatively few *L. higginsi* have been found in Pool 17; none were collected during the 1990 study year. Quantitative and qualitative sampling have indicated that these beds are characterized by moderate to high density, diversity, and evenness. There were measurable deferences between near and farshore assemblages. Densities were greatest at the central portion of the bed, less near the thalweg and the shore. *Amblema plicata* tended to dominate near the shore; *L. ventricosa* tended to dominate in the deeper water. All of these mussel beds are adjacent to navigation lanes, however no recently settled sediments, indications of benthic scour, or evidence of shell abrasion from vessel passage were noted.

69. Physical effects studies have been conducted since 1989. Vessel passage causes an alteration of velocity parallel and at right angles to flow. Typically, the ambient velocity increases by two or three times as a result of passage; rarely does velocity increase above 2 ft/sec at the substrate-water interface following vessel passage. It should be recognized that movement of commercial vessels can cause considerable turbulence and velocity change in the thalweg; however, dramatic changes have not been noted immediately above dense and diverse mussel beds. Results of studies on effects of passage of water turbidity indicate that vessel movement causes turbidity to approximately double near the surface-water interface. However, ambient turbidity levels usually return within 5 min.

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APPENDIX A: FRESHWATER BIVALVES COLLECTED IN THE UPPER MISSISSIPPI RIVER (UMR) IN 1990 USING QUALITATIVE TECHNIQUES

Table A1

Relative Abundance of Freshwater Mussels Collected Using Qualitative Techniques at UMR Mile 448.7, Pool 17, July 1990

Species	Subsite A*	Subsite B*	Total for Site
A. plicata	0.0877	0.2973	0.2174
M. gigantea	0.0000	0.0649	0.0401
Q. pustulosa	0.1491	0.1351	0.1405
L. fragilis	0.0088	0.0595	0.0401
Q. quadrula	0.0088	0.0378	0.0268
L. ventricosa	0.1667	0.0649	0.1037
E. lineolata	0.0439	0.0486	0.0468
O. olivaria	0.2807	0.0378	0.1304
P. alatus	0.0088	0.0811	0.0535
F. flava	0.0000	0.0324	0.0201
A. ligamentina	0.0175	0.0486	0.0368
A. grandis	0.0088	0.0108	0.0100
Q. metanevra	0.1316	0.0270	0.0669
L. recta	0.0000	0.0162	0.0100
O. reflexa	0.0702	0.0162	0.0368
T. truncata	0.0088	0.0000	0.0033
A. confragosus	0.0000	0.0054	0.0033
S. undulatus	0.0088	0.0162	0.0134
Total individuals	114	185	299

* Twelve samples were collected at subsites A and B. Relative species abundances were calculated for each subsite and for all subsites combined (total for site).

Table A2

Relative Abundance of Freshwater Mussels Collected Using Qualitative Techniques at UMR Mile 450.4, Pool 17, July 1990

Species	Subsite A*	Subsite B*	Subsite C*	Total for Site
A. plicata	0.2172	0.2903	0.3607	0.2787
M. nervosa	0.0960	0.0699	0.0984	0.0870
Q. pustulosa	0.0758	0.1398	0.1557	0.1186
L. fragilis	0.2879	0.1398	0.0984	0.1877
Q. quadrula	0.0354	0.0376	0.0328	0.0356
L. ventricosa	0.0354	0.0161	0.0082	0.0217
E. lineolata	0.0758	0.1075	0.0902	0.0909
O. olivaria	0.0152	0.0054	0.0246	0.0138
P. alatus	0.0253	0.0215	0.0246	0.0237
F. flava	0.0101	0.0108	0.0082	0.0099
A. ligamentina	0.0606	0.0161	0.0328	0.0375
A. grandis	0.0202	0.0484	0.0246	0.0316
Q. metanevra	0.0152	0.0269	0.0246	0.0217
L. recta	0.0152	0.0000	0.0000	0.0059
O. reflexa	0.0000	0.0161	0.0000	0.0059
T. truncata	0.0051	0.0108	0.0082	0.0079
A. confragosus	0.0000	0.0108	0.0082	0.0059
S. undulatus	0.0051	0.0323	0.0000	0.0138
Total individuals	198	186	122	506

* Twelve samples were collected at subsites A, B, and C. Relative species abundances were calculated for each subsite and for all subsites combined (total for site).

Table A3

Relative Abundance of Freshwater Mussels Collected Using Qualitative Techniques at UMR Mile 571.5, Pool 17, July 1990

Species	Subsite A*	Subsite B*	Subsite C*	Total for Site
A. plicata	0.4610	0.3687	0.3459	0.3880
M. nervosa	0.0974	0.1732	0.2000	0.1602
Q. pustulosa	0.0000	0.0335	0.0162	0.0174
L. fragilis	0.0065	0.0112	0.0054	0.0077
Q. quadrula	0.0844	0.1229	0.1297	0.1139
L. ventricosa	0.0390	0.0279	0.0595	0.0425
E. lineolata	0.0065	0.0112	0.0054	0.0077
O. olivaria	0.0000	0.0503	0.0216	0.0251
P. alatus	0.0130	0.0056	0.0108	0.0097
F. flava	0.0519	0.0391	0.0324	0.0405
A. ligamentina	0.0000	0.0056	0.0054	0.0039
A. grandis	0.0779	0.0056	0.0000	0.0251
Q. metanevra	0.0000	0.0000	0.0054	0.0019
L. recta	0.0325	0.0335	0.0757	0.0483
O. reflexa	0.0195	0.0391	0.0108	0.0232
T. truncata	0.0390	0.0335	0.0162	0.0290
A. confragosus	0.0260	0.0223	0.0270	0.0251
S. undulatus	0.0065	0.0000	0.0000	0.0019
L. higginsi	0.0130	0.0000	0.0162	0.0097
Q. nodulata	0.0065	0.0056	0.0108	0.0077
A. corpulenta	0.0195	0.0000	0.0000	0.0058
L. complanata	0.0000	0.0112	0.0054	0.0058
Total individuals	154	179	185	518

* Twelve samples were collected at subsites A, B, and C. Relative species abundances were calculated for each subsite and for all subsites combined (total for site).

Table A4

Frequency of Occurrence of Freshwater Bivalves Collected Using Qualitative Techniques at UMR Mile 448.7, Pool 17, July 1990

Species	Subsite A*	Subsite B*	Total for Site
A. plicata	0.5556	1.0000	0.8095
M. nervosa	0.0000	0.5000	0.2857
Q. pustulosa	0.6667	1.0000	0.8571
Q. quadrula	0.1111	0.5000	0.3333
L. ventricosa	0.6667	0.6667	0.6667
E. lineolata	0.4444	0.4167	0.4286
L. fragilis	0.1111	0.5833	0.3810
O. olivaria	0.8889	0.5000	0.6667
A. ligamentina	0.1111	0.5000	0.3333
L. recta	0.0000	0.2500	0.1429
P. alatus	0.1111	0.5000	0.3333
Q. metanevra	0.5556	0.4167	0.4762
A. grandis	0.1111	0.1667	0.1429
F. flava	0.0000	0.2500	0.1429
O. reflexa	0.5556	0.2500	0.3810
T. truncata	0.1111	0.0000	0.0476
A. confragosus	0.0000	0.0833	0.0476
S. undulatus	0.1111	0.2500	0.1905
Total samples	9	12	21

* Sampling locations (Table 2).

Table A5

Frequency of Occurrence of Freshwater Bivalves Collected Using Qualitative Techniques at UMR Mile 450.4, Pool 17, July 1990

Species	Subsite A*	Subsite B*	Total for Site
A. plicata	0.9167	0.8500	0.8750
M. nervosa	0.7500	0.7500	0.7500
Q. pustulosa	0.8333	0.8000	0.8125
Q. quadrula	0.3333	0.4500	0.4063
L. ventricosa	0.4167	0.2000	0.2813
E. lineolata	0.6667	0.8000	0.7500
L. fragilis	1.0000	0.6000	0.7500
O. olivaria	0.2500	0.1500	0.1875
A. ligamentina	0.6667	0.3000	0.4375
L. recta	0.1667	0.0000	0.0625
P. alatus	0.2500	0.3000	0.2813
Q. metanevra	0.1667	0.4000	0.3125
A. grandis	0.3333	0.3500	0.3438
F. flava	0.1667	0.1500	0.1563
O. reflexa	0.0000	0.1000	0.0625
T. truncata	0.0833	0.1500	0.1250
A. confragosus	0.0000	0.1500	0.0938
S. undulatus	0.0833	0.3000	0.2188
P. laevissima	0.0833	0.0000	0.0313
Total samples	12	20	32

* Sampling locations (Table 2).

Table A6

Frequency of Occurrence of Freshwater Bivalves Collected Using Qualitative Techniques at UMR Mile 571.5, Pool 12, July 1990

Species	Subsite A*	Subsite B*	Subsite C*	Total for Site
A. plicata	0.6667	1.0000	1.0000	0.8889
M. nervosa	0.3333	0.8333	0.8333	0.6667
Q. pustulosa	0.0000	0.4167	0.1667	0.1944
Q. quadrula	0.3333	0.8333	0.7500	0.6389
L. ventricosa	0.2500	0.4167	0.5833	0.4167
E. lineolata	0.0000	0.1667	0.0833	0.0833
L. fragilis	0.0000	0.1667	0.0833	0.0833
O. olivaria	0.0000	0.5833	0.3333	0.3056
A. ligamentina	0.0000	0.0833	0.0833	0.0556
L. recta	0.2500	0.4167	0.7500	0.4722
P. alatus	0.1667	0.0833	0.1667	0.1389
Q. metanevra	0.0000	0.0000	0.0833	0.0278
A. grandis	0.4167	0.0833	0.0000	0.1667
F. flava	0.3333	0.4167	0.2500	0.3333
O. reflexa	0.0833	0.4167	0.1667	0.2222
T. truncata	0.3333	0.2500	0.2500	0.2778
A. confragosus	0.1667	0.2500	0.3333	0.2500
L. higginsi	0.0833	0.0000	0.2500	0.1111
L. complanata	0.0000	0.1667	0.0833	0.0833
Q. nodulata	0.0000	0.0833	0.1667	0.0833
A. corpulenta	0.1667	0.0000	0.0000	0.0556
Total samples	12	12	12	36

* Sampling locations (Table 2).

APPENDIX B: FRESHWATER BIVALVES COLLECTED IN THE UPPER MISSISSIPPI RIVER (UMR) IN JULY 1990 USING QUANTITATIVE TECHNIQUES

Table B1

Relative Species Abundance of Mussels Collected Using Quantitative Techniques at UMR Mile 450.4, Pool 17, 75 ft from the Right Descending Bank (Nearshore Site)

Species	Subsite A*	Subsite B*	Subsite C*	Total for Site
A. plicata	0.1957	0.1570	0.2531	0.2028
T. truncata	C.1875	0.2066	0.2099	0.1966
E. lineolata	0.1304	0.1983	0.1358	0.1444
Q. pustulosa	0.1196	0.1157	0.1296	0.1214
O. reflexa	0.0815	0.0992	0.0556	0.0783
L. fragilis	0.0516	0.0248	0.0617	0.0492
M. nervosa	0.0435	0.0083	0.0309	0.0338
T. donaciformis	0.0326	0.0579	0.0000	0.0292
Q. quadrula	0.0326	0.0083	0.0123	0.0230
F. flava	0.0190	0.0165	0.0185	0.0184
Q. metanevra	0.0217	0.0083	0.0185	0.0184
O. olivaria	0.0109	0.0165	0.0247	0.0154
A. grandis	0.0190	0.0000	0.0123	0.0138
P. alatus	0.0054	0.0413	0.0000	0.0108
A. ligamentina	0.0082	0.0165	0.0062	0.0092
S. undulatus	0.0054	0.0083	0.0062	0.0061
Q. nodulata	0.0109	0.0000	0.0000	0.0061
A. imbecillis	0.0109	0.0000	0.0000	0.0061
L. ventricosa	0.0082	0.0000	0.0062	0.0061
L. complanata	0.0000	0.0000	0.0123	0.0031
A. confragosus	0.0027	0.0000	0.0062	0.0031
L. recta	0.0000	0.0165	0.0000	0.0031
C. parva	0.0027	0.0000	0.0000	0.0015

Summary Statistics**

	A	B	C	Total
Total individuals	368	121	162	651
Total species	21	16	17	23
Total samples	10	10	10	30
Diversity (H')				2.381
Evenness (J)				0.760
Total individuals < 30 mm total shell length				12.0%
Total species < 30 mm total shell length				52.2%

* Ten samples were collected at Subsites A, B, and C. Relative species abundances were calculated for each subsite and for all subsites combined (total for site).

** Summary statistics (diversity, evenness, etc.) were calculated for all subsites combined.

Table B2

Relative Species Abundance of Mussels Collected Using Quantitative Techniques at UMR Mile 450.4, Pool 17, 120 ft from the Right Descending Bank (Farshore Site)

Species	Subsite A*	Subsite B*	Subsite C*	Total for Site
A. plicata	0.1250	0.3874	0.1645	0.2528
Q. pustulosa	0.0833	0.1623	0.0789	0.1162
L. fragilis	0.1458	0.0628	0.1250	0.1025
E. lineolata	0.1146	0.1099	0.0592	0.0934
T. truncata	0.0833	0.0628	0.0987	0.0797
T. donaciformis	0.1458	0.0262	0.0789	0.0706
M. nervosa	0.1146	0.0262	0.0658	0.0592
Q. quadrula	0.0208	0.0471	0.0395	0.0387
O. reflexa	0.0208	0.0524	0.0329	0.0387
A. grandis	0.0208	0.0105	0.0789	0.0364
P. alatus	0.0313	0.0052	0.0724	0.0342
O. olivaria	0.0313	0.0105	0.0132	0.0159
Q. metanevra	0.0208	0.0052	0.0197	0.0137
F. flava	0.0208	0.0105	0.0066	0.0114
P. laevissima	0.0104	0.0000	0.0132	0.0068
A. confragosus	0.0000	0.0052	0.0066	0.0046
A. ligamentina	0.0000	0.0000	0.0132	0.0046
C. fluminea	0.0104	0.0000	0.0066	0.0046
L. ventricosa	0.0000	0.0000	0.0132	0.0046
S. undulatus	0.0000	0.0000	0.0066	0.0023
C. parva	0.0000	0.0052	0.0000	0.0023
P. cyphyus	0.0000	0.0052	0.0066	0.0023
P. sintoxia	0.0000	0.0052	0.0000	0.0023
L. complanata	0.0000	0.0000	0.0066	0.0023

Summary Statistics**

	A	B	C	Total for Site
Total individuals	96	191	152	439
Total species	16	18	21	24
Total samples	10	10	10	30
Diversity (H')				2.473
Evenness (J)				0.778
Total individuals < 30 mm total shell length				13.7%
Total species < 30 mm total shell length				50.0%

* Ten samples were collected at Subsites A, B, and C. Relative species abundances were calculated for each subsite and for all subsites combined (total for site).

** Summary statistics (diversity, evenness, etc.) were calculated for all subsites combined.

Table B3

Relative Species Abundance of Mussels Collected Using Quantitative Techniques at UMR Mile 571.5, Pool 12, 140 ft from the Right Descending Bank (Nearshore Site)

Species	Subsite A*	Subsite B*	Total for Site
A. plicata	0.5600	0.4318	0.4783
C. parva	0.0800	0.1818	0.1449
F. flava	0.0400	0.0227	0.0290
O. reflexa	0.3200	0.2500	0.2754
L. fragilis	0.0000	0.0455	0.0290
Q. quadrula	0.0000	0.0145	0.0145
T. truncata	0.0000	0.0290	0.0290
Summary Statistics**			
Total individuals	25	44	69
Total species	4	7	7
Total samples	10	10	20
Diversity (H')			1.356
Evenness (J)			0.697
Total individuals < 30 mm total shell length			44.9%
Total species < 30 mm total shell length			71.4%

* Ten samples were collected at Subsites A, B, and C. Relative species abundances were calculated for each subsite and for all subsites combined (total for site).

** Summary statistics (diversity, evenness, etc.) were calculated for all subsites combined.

Table B4

Relative Species Abundance of Mussels Collected Using Quantitative Tecnniques at UMR Mile 571.5, Pool 12, 200 ft from the Right Descending Bank (Center Site)

Species	Subsite A*	Subsite B*	Total for Site
A. plicata	0.2188	0.2174	0.2182
C. fluminea	0.0156	0.0000	0.0091
F. flava	0.0313	0.0435	0.0364
L. higginsi	0.0156	0.0000	0.0091
L. radiata	0.0469	0.0000	0.0273
L. fragilis	0.0156	0.0217	0.0182
L. recta	0.0469	0.0000	0.0273
M. nervosa	0.1094	0.1087	0.1091
O. reflexa	0.1406	0.2609	0.1909
O. olivaria	0.0625	0.0000	0.0364
Q. pustulosa	0.0156	0.0217	0.0182
Q. quadrula	0.1250	0.0435	0.0909
S. undulatus	0.0156	0.0000	0.0091
T. donaciformis	0.0156	0.0000	0.0091
T. truncata	0.1250	0.2174	0.1636
A. grandis	0.0000	0.0435	0.0182
E. lineolata	0.0000	0.0217	0.0091
Summary Statistics**			
Total individuals	64	46	110
Total species	15	10	17
Total samples	10	10	20
Diversity (H')			2.351
Evenness (J)			0.799
Total individuals < 30 mm total shell length			28.2%
Total species < 30 mm total shell length			40.0%

* Ten samples were collected at Subsites A, B, and C. Relat. e species abundances were calculated for each subsite and for all subsites combined (total for site).

** Summary statistics (diversity, evenness, etc.) were calculated for all subsites combined.

Table B5

Relative Species Abundance of Mussels Collected Using Quantitative Techniques at UMR Mile 571.5, Pool 12, 350 ft from the Right Descending Bank (Farshore Site)

Species	Subsite A*	Subsite B*	Total for Site
A. plicata	0.1982	0.2373	0.2183
A. grandis	0.0180	0.0169	0.0175
E. lineolata	0.0450	0.0339	0.0393
F. flava	0.0450	0.0932	0.0699
L. radiata	0.0090	0.0085	0.0087
L. ventricosa	0.0180	0.0169	0.0175
L. complanata	0.0180	0.0000	0.0087
L. fragilis	0.0270	0.0508	0.0393
L. recta	0.0090	0.0085	0.0087
M. nervosa	0.0721	0.0932	0.0830
O. reflexa	0.0631	0.0424	0.0524
O. olivaria	0.0450	0.0339	0.0393
Q. pustulosa	0.1441	0.0169	0.0087
S. undulatus	0.0090	0.0085	0.0087
T. donaciformis	0.0270	0.0339	0.0306
T. truncata	0.2523	0.1864	0.2183
P. alatus	0.0000	0.0085	0.0044
Q. metanevra	0.0000	0.0085	0.0044
Q. quadrula	0.0000	0.1017	0.1223

Summary Statistics**

Total individuals	111	118	229
Total species	16	18	19
Total samples	20		
Diversity (H')			2.351
Evenness (J)			0.799
Total individuals < 30 mm total shell length			17.9%
Total species < 30 mm total shell length			47.4%

* Ten samples were collected at Subsites A, B, and C. Relative species abundances were calculated for each subsite and for all subsites combined (total for site).

** Summary statistics (diversity, evenness, etc.) were calculated for all subsites combined.

Table B6

Number of Fresh Dead Mussels (Tissue Present) in Quantitative Samples Collected at UMR Miles 571.5 and 450.4, July 1990

	Subsite		
	A	B	C
RM 450.4			
Nearshore	0	0	1
Farshore	1	0	0
RM 571.5			
Nearshore	0	0	
Middle	1	0	
Farshore	0	0	

APPENDIX C: LENGTH-FREQUENCY HISTOGRAMS FOR BIVALVES COLLECTED IN THE UPPER MISSISSIPPI RIVER (UMR), JULY 1990

LOC=806 SPECIES=AMBLEMA PLICATA

PERCENTAGE OF SHELLEN

SHELLEN		FREQ	CUM FREQ	PERCENT	CUM PERCENT
0		0	0	0.00	0.00
2		0	0	0.00	0.00
4		0	0	0.00	0.00
6		0	0	0.00	0.00
8		0	0	0.00	0.00
10		0	0	0.00	0.00
12		0	0	0.00	0.00
14	********	5	5	2.06	2.06
16	***	2	7	0.82	2.88
18	********	5	12	2.06	4.94
20	**	1	13	0.41	5.35
22		0	13	0.00	5.35
24	**	1	14	0.41	5.76
26	**	1	15	0.41	6.17
28		0	15	0.00	6.17
30		0	15	0.00	6.17
32	***	2	17	0.82	7.00
34	***	2	19	0.82	7.82
36	*******	4	23	1.65	9.47
38	**	1	24	0.41	9.88
40	*****	3	27	1.23	11.11
42	***	2	29	0.82	11.93
44	*****	3	32	1.23	13.17
46	***	2	34	0.82	13.99
48	********	5	39	2.06	16.05
50	************	7	46	2.88	18.93
52	*****	3	49	1.23	20.16
54	**	1	50	0.41	20.58
56	**********	6	56	2.47	23.05
58	*****	3	59	1.23	24.28
60	*************	8	67	3.29	27.57
62	*****	3	70	1.23	28.81
64	********	5	75	2.06	30.86
66	************	7	82	2.88	33.74
68	************	7	89	2.88	36.63
70	****************	10	99	4.12	40.74
72	********************	12	111	4.94	45.68
74	**************************	16	127	6.58	52.26
76	**************************	16	143	6.58	58.85
78	*************************	15	158	6.17	65.02
80	*********************************	20	178	8.23	73.25
82	***********************	14	192	5.76	79.01
84	*******************************	19	211	7.82	86.83
86	********************	12	223	4.94	91.77
88	**********	6	229	2.47	94.24
90	**********	6	235	2.47	96.71
92	***	2	237	0.82	97.53
94	**	1	238	0.41	97.94
96	*******	4	242	1.65	99.59
98		0	242	0.00	99.59
100		0	242	0.00	99.59
102	**	1	243	0.41	100.00
104		0	243	0.00	100.00
106		0	243	0.00	100.00
108		0	243	0.00	100.00

----+---+---+---+---+---+---+---+-

1 2 3 4 5 6 7 8

Figure C1. Amblema plicata collected at UMR mile 450.4, July 1990

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-------------------- LOC=807 SPECIES=AMBLEMA PLICATA --------------------

                     PERCENTAGE OF SHELLEN

SHELLEN                                            CUM              CUM
                                           FREQ   FREQ  PERCENT  PERCENT

     8  |                                     0      0     0.00     0.00
    10  |                                     0      0     0.00     0.00
    12  |                                     0      0     0.00     0.00
    14  |*****                                1      1     0.93     0.93
    16  |                                     0      1     0.00     0.93
    18  |*****                                1      2     0.93     1.87
    20  |*********                            2      4     1.87     3.74
    22  |**********************               5      9     4.67     8.41
    24  |**************                       3     12     2.80    11.21
    26  |*********                            2     14     1.87    13.08
    28  |*********                            2     16     1.87    14.95
    30  |*****                                1     17     0.93    15.89
    32  |**************                       3     20     2.80    18.69
    34  |*****                                1     21     0.93    19.63
    36  |**************                       3     24     2.80    22.43
    38  |*****                                1     25     0.93    23.36
    40  |*********                            2     27     1.87    25.23
    42  |**************                       3     30     2.80    28.04
    44  |******************                   4     34     3.74    31.78
    46  |******************                   4     38     3.74    35.51
    48  |                                     0     38     0.00    35.51
    50  |*********                            2     40     1.87    37.38
    52  |*********                            2     42     1.87    39.25
    54  |*********                            2     44     1.87    41.12
    56  |*****                                1     45     0.93    42.06
    58  |*********                            2     47     1.87    43.93
    60  |**************                       3     50     2.80    46.73
    62  |*********                            2     52     1.87    48.60
    64  |**********************               5     57     4.67    53.27
    66  |******************                   4     61     3.74    57.01
    68  |**************                       3     64     2.80    59.81
    70  |**************                       3     67     2.80    62.62
    72  |                                     0     67     0.00    62.62
    74  |*****                                1     68     0.93    63.55
    76  |***************************          6     74     5.61    69.16
    78  |*********                            2     76     1.87    71.03
    80  |*****                                1     77     0.93    71.96
    82  |**********************               5     82     4.67    76.64
    84  |***************************          6     88     5.61    82.24
    86  |**********************               5     93     4.67    86.92
    88  |                                     0     93     0.00    86.92
    90  |**********************               5     98     4.67    91.59
    92  |**************                       3    101     2.80    94.39
    94  |                                     0    101     0.00    94.39
    96  |                                     0    101     0.00    94.39
    98  |                                     0    101     0.00    94.39
   100  |*********                            2    103     1.87    96.26
   102  |*********                            2    105     1.87    98.13
   104  |*********                            2    107     1.87   100.00
   106  |                                     0    107     0.00   100.00
   108  |                                     0    107     0.00   100.00
   110  |                                     0    107     0.00   100.00
         -----+----+----+----+----+---
              1    2    3    4    5
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Figure C2. _Amblema_ _plicata_ collected at UMR mile 571.5, July 1990

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------------------- LOC=806 SPECIES=ELLIPSARIA LINEOLATA -------------------

                        PERCENTAGE OF SHELLEN

SHELLEN                                                    CUM            CUM
                                                    FREQ  FREQ PERCENT PERCENT

   10  |                                               0     0   0.00    0.00
   12  |                                               0     0   0.00    0.00
   14  |                                               0     0   0.00    0.00
   16  |***                                            1     1   0.74    0.74
   18  |                                               0     1   0.00    0.74
   20  |                                               0     1   0.00    0.74
   22  |                                               0     1   0.00    0.74
   24  |                                               0     1   0.00    0.74
   26  |***                                            1     2   0.74    1.48
   28  |                                               0     2   0.00    1.48
   30  |*********                                      3     5   2.22    3.70
   32  |***************                                5    10   3.70    7.41
   34  |******                                         2    12   1.48    8.89
   36  |************                                   4    16   2.96   11.85
   38  |************************************          12    28   8.89   20.74
   40  |***************************                    9    37   6.67   27.41
   42  |***************************                    9    46   6.67   34.07
   44  |************************************          12    58   8.89   42.96
   46  |***************************************       13    71   9.63   52.59
   48  |************************                       8    79   5.93   58.52
   50  |************************                       8    87   5.93   64.44
   52  |*********************                          7    94   5.19   69.63
   54  |************************                       8   102   5.93   75.56
   56  |*********                                      3   105   2.22   77.78
   58  |******************                             6   111   4.44   82.22
   60  |***                                            1   112   0.74   82.96
   62  |******                                         2   114   1.48   84.44
   64  |*********************                          7   121   5.19   89.63
   66  |*********                                      3   124   2.22   91.85
   68  |******                                         2   126   1.48   93.33
   70  |******                                         2   128   1.48   94.81
   72  |************                                   4   132   2.96   97.78
   74  |***                                            1   133   0.74   98.52
   76  |***                                            1   134   0.74   99.26
   78  |                                               0   134   0.00   99.26
   80  |                                               0   134   0.00   99.26
   82  |                                               0   134   0.00   99.26
   84  |                                               0   134   0.00   99.26
   86  |                                               0   134   0.00   99.26
   88  |***                                            1   135   0.74  100.00
   90  |                                               0   135   0.00  100.00
   92  |                                               0   135   0.00  100.00
   94  |                                               0   135   0.00  100.00
   96  |                                               0   135   0.00  100.00
       ----+---+---+---+---+---+---+---+---+---
           1   2   3   4   5   6   7   8   9
```

Figure C3. _Ellipsaria_ _lineolata_ collected at UMR mile 450.4, July 1990

```
-------------------- LOC=806 SPECIES=LEPTODEA FRAGILIS --------------------
                         PERCENTAGE OF SHELLEN

SHELLEN                                                      CUM             CUM
                                                     FREQ   FREQ  PERCENT  PERCENT

   18  |                                                0      0     0.00     0.00
   20  |                                                0      0     0.00     0.00
   22  |                                                0      0     0.00     0.00
   24  |******                                          1      1     1.30     1.30
   26  |*************                                   2      3     2.60     3.90
   28  |                                                0      3     0.00     3.90
   30  |                                                0      3     0.00     3.90
   32  |                                                0      3     0.00     3.90
   34  |                                                0      3     0.00     3.90
   36  |                                                0      3     0.00     3.90
   38  |******                                          1      4     1.30     5.19
   40  |*******************                             3      7     3.90     9.09
   42  |*************                                   2      9     2.60    11.69
   44  |**************************                      4     13     5.19    16.88
   46  |*******************                             3     16     3.90    20.78
   48  |*************                                   2     18     2.60    23.38
   50  |*************                                   2     20     2.60    25.97
   52  |*************                                   2     22     2.60    28.57
   54  |********************************                5     27     6.49    35.06
   56  |*******************                             3     30     3.90    38.96
   58  |*************                                   2     32     2.60    41.56
   60  |***************************************         6     38     7.79    49.35
   62  |                                                0     38     0.00    49.35
   64  |*************                                   2     40     2.60    51.95
   66  |******                                          1     41     1.30    53.25
   68  |*******************                             3     44     3.90    57.14
   70  |*************                                   2     46     2.60    59.74
   72  |*************                                   2     48     2.60    62.34
   74  |**************************                      4     52     5.19    67.53
   76  |**************************                      4     56     5.19    72.73
   78  |*************                                   2     58     2.60    75.32
   80  |*******************                             3     61     3.90    79.22
   82  |*************                                   2     63     2.60    81.82
   84  |*******************                             3     66     3.90    85.71
   86  |*******************                             3     69     3.90    89.61
   88  |*******************                             3     72     3.90    93.51
   90  |******                                          1     73     1.30    94.81
   92  |******                                          1     74     1.30    96.10
   94  |*************                                   2     76     2.60    98.70
   96  |                                                0     76     0.00    98.70
   98  |                                                0     76     0.00    98.70
  100  |******                                          1     77     1.30   100.00
  102  |                                                0     77     0.00   100.00
        -----+----+----+----+----+----+----+----
             1    2    3    4    5    6    7
```

Figure C4. _Leptodea_ _fragilis_ collected at UMR mile 450.4, July 1990

------------------- LOC=806 SPECIES=MEGALONAIAS NERVOSA -------------------

PERCENTAGE OF SHELLEN

SHELLEN		FREQ	CUM FREQ	PERCENT	CUM PERCENT
36		0	0	0.00	0.00
38	********	2	2	4.17	4.17
40		0	2	0.00	4.17
42		0	2	0.00	4.17
44		0	2	0.00	4.17
46		0	2	0.00	4.17
48	****	1	3	2.08	6.25
50	********	2	5	4.17	10.42
52	*****************	4	9	8.33	18.75
54	****	1	10	2.08	20.83
56	*************	3	13	6.25	27.08
58	*********************	5	18	10.42	37.50
60	********	2	20	4.17	41.67
62		0	20	0.00	41.67
64	*****************	4	24	8.33	50.00
66	****	1	25	2.08	52.08
68	********	2	27	4.17	56.25
70	********	2	29	4.17	60.42
72	********	2	31	4.17	64.58
74	****	1	32	2.08	66.67
76	****	1	33	2.08	68.75
78	********	2	35	4.17	72.92
80	****	1	36	2.08	75.00
82		0	36	0.00	75.00
84	*************	3	39	6.25	81.25
86		0	39	0.00	81.25
88		0	39	0.00	81.25
90	****	1	40	2.08	83.33
92	****	1	41	2.08	85.42
94	*************	3	44	6.25	91.67
96		0	44	0.00	91.67
98	****	1	45	2.08	93.75
100		0	45	0.00	93.75
102		0	45	0.00	93.75
104	****	1	46	2.08	95.83
106		0	46	0.00	95.83
108		0	46	0.00	95.83
110		0	46	0.00	95.83
112		0	46	0.00	95.83
114		0	46	0.00	95.83
116		0	46	0.00	95.83
118		0	46	0.00	95.83
120		0	46	0.00	95.83
122		0	46	0.00	95.83
124		0	46	0.00	95.83
126		0	46	0.00	95.83
128		0	46	0.00	95.83
130		0	46	0.00	95.83
132		0	46	0.00	95.83
134		0	46	0.00	95.83
136		0	46	0.00	95.83
138		0	46	0.00	95.83
140		0	46	0.00	95.83
142		0	46	0.00	95.83
144		0	46	0.00	95.83
146		0	46	0.00	95.83
148		0	46	0.00	95.83
150		0	46	0.00	95.83
152		0	46	0.00	95.83
154	****	1	47	2.08	97.92
156		0	47	0.00	97.92
158		0	47	0.00	97.92
160		0	47	0.00	97.92
162	****	1	48	2.08	100.00
164		0	48	0.00	100.00
	----+---+---+---+---+-				
	2 4 6 8 10				

Figure C5. *Megalonaias nervosa* collected at UMR mile 450.4, July 1990

```
------------------- LOC=807 SPECIES=MEGALONAIAS NERVOSA -------------------
                              PERCENTAGE OF SHELLEN
SHELLEN                                                     CUM               CUM
                                                     FREQ   FREQ   PERCENT   PERCENT

   52   |                                             0      0      0.00      0.00
   54   |**************************                   2      2      6.45      6.45
   56   |                                             0      2      0.00      6.45
   58   |*************                                1      3      3.23      9.68
   60   |*************                                1      4      3.23     12.90
   62   |                                             0      4      0.00     12.90
   64   |                                             0      4      0.00     12.90
   66   |*************                                1      5      3.23     16.13
   68   |                                             0      5      0.00     16.13
   70   |***************************************      3      8      9.68     25.81
   72   |                                             0      8      0.00     25.81
   74   |                                             0      8      0.00     25.81
   76   |                                             0      8      0.00     25.81
   78   |                                             0      8      0.00     25.81
   80   |**************************                   2     10      6.45     32.26
   82   |*************                                1     11      3.23     35.48
   84   |                                             0     11      0.00     35.48
   86   |*************                                1     12      3.23     38.71
   88   |**************************                   2     14      6.45     45.16
   90   |                                             0     14      0.00     45.16
   92   |*************                                1     15      3.23     48.39
   94   |                                             0     15      0.00     48.39
   96   |*************                                1     16      3.23     51.61
   98   |                                             0     16      0.00     51.61
  100   |**************************                   2     18      6.45     58.06
  102   |*************                                1     19      3.23     61.29
  104   |                                             0     19      0.00     61.29
  106   |**************************                   2     21      6.45     67.74
  108   |*************                                1     22      3.23     70.97
  110   |*************                                1     23      3.23     74.19
  112   |*************                                1     24      3.23     77.42
  114   |**************************                   2     26      6.45     83.87
  116   |*************                                1     27      3.23     87.10
  118   |                                             0     27      0.00     87.10
  120   |                                             0     27      0.00     87.10
  122   |                                             0     27      0.00     87.10
  124   |                                             0     27      0.00     87.10
  126   |                                             0     27      0.00     87.10
  128   |*************                                1     28      3.23     90.32
  130   |*************                                1     29      3.23     93.55
  132   |                                             0     29      0.00     93.55
  134   |                                             0     29      0.00     93.55
  136   |*************                                1     30      3.23     96.77
  138   |                                             0     30      0.00     96.77
  140   |                                             0     30      0.00     96.77
  142   |                                             0     30      0.00     96.77
  144   |                                             0     30      0.00     96.77
  146   |                                             0     30      0.00     96.77
  148   |                                             0     30      0.00     96.77
  150   |                                             0     30      0.00     96.77
  152   |*************                                1     31      3.23    100.00
  154   |                                             0     31      0.00    100.00
  156   |                                             0     31      0.00    100.00
         ----+---+---+- -+---+---+---+---+---+---
             1   2   3   4   5   6   7   8   9
```

Figure C6. *Megalonaias nervosa* collected at UMR mile 571.5, July 1990

-------------------- LOC=806 SPECIES=OBLIQUARIA REFLEXA --------------------

PERCENTAGE OF SHELLEN

SHELLEN		FREQ	CUM FREQ	PERCENT	CUM PERCENT
10		0	0	0.00	0.00
12		0	0	0.00	0.00
14		0	0	0.00	0.00
16		0	0	0.00	0.00
18		0	0	0.00	0.00
20	*********	3	3	4.41	4.41
22		0	3	0.00	4.41
24		0	3	0.00	4.41
26		0	3	0.00	4.41
28	***	1	4	1.47	5.88
30	******	2	6	2.94	8.82
32	*********	3	9	4.41	13.24
34	*********************	7	16	10.29	23.53
36	***************************************	13	29	19.12	42.65
38	******************************	10	39	14.71	57.35
40	************************	8	47	11.76	69.12
42	*********************	7	54	10.29	79.41
44	******************	6	60	8.82	88.24
46	*********	3	63	4.41	92.65
48	*********	3	66	4.41	97.06
50	***	1	67	1.47	98.53
52		0	67	0.00	98.53
54		0	67	0.00	98.53
56		0	67	0.00	98.53
58		0	67	0.00	98.53
60		0	67	0.00	98.53
62		0	67	0.00	98.53
64		0	67	0.00	98.53
66		0	67	0.00	98.53
68	***	1	68	1.47	100.00
70		0	68	0.00	100.00
72		0	68	0.00	100.00
74		0	68	0.00	100.00
76		0	68	0.00	100.00

```
----+---+---+---+---+---+---+---+---+--
    2   4   6   8  10  12  14  16  18
```

Figure C7. _Obliquaria_ _reflexa_ collected at UMR mile 450.4, July 1990

-------------------- LOC=807 SPECIES=OBLIQUARIA REFLEXA --------------------

PERCENTAGE OF SHELLEN

SHELLEN		FREQ	CUM FREQ	PERCENT	CUM PERCENT
4		0	0	0.00	0.00
6		0	0	0.00	0.00
8		0	0	0.00	0.00
10	****	1	1	1.92	1.92
12		0	1	0.00	1.92
14	********	2	3	3.85	5.77
16		0	3	0.00	5.77
18	********	2	5	3.85	9.62
20	********	2	7	3.85	13.46
22	****	1	8	1.92	15.38
24	***********************************	9	17	17.31	32.69
26	***************	4	21	7.69	40.38
28	***************	4	25	7.69	48.08
30	********	2	27	3.85	51.92
32		0	27	0.00	51.92
34	*******************************	8	35	15.38	67.31
36	************	3	38	5.77	73.08
38	************	3	41	5.77	78.85
40	********	2	43	3.85	82.69
42	****	1	44	1.92	84.62
44	********	2	46	3.85	88.46
46	************	3	49	5.77	94.23
48		0	49	0.00	94.23
50	************	3	52	5.77	100.00
52		0	52	0.00	100.00
54		0	52	0.00	100.00
56		0	52	0.00	100.00
	2 4 6 8 10 12 14 16				

Figure C8. Obliquaria reflexa collected at UMR mile 571.5, July 1990

------------------- LOC=806 SPECIES=QUADRULA PUSTULOSA -------------------

PERCENTAGE OF SHELLEN

SHELLEN		FREQ	CUM FREQ	PERCENT	CUM PERCENT
14		0	0	0.00	0.00
16		0	0	0.00	0.00
18		0	0	0.00	0.00
20		0	0	0.00	0.00
22	************	4	4	3.08	3.08
24	******************	6	10	4.62	7.69
26	***	1	11	0.77	8.46
28	******************	6	17	4.62	13.08
30	******	2	19	1.54	14.62
32	************	4	23	3.08	17.69
34	******************	6	29	4.62	22.31
36	*********	3	32	2.31	24.62
38	***************************	9	41	6.92	31.54
40	************************	8	49	6.15	37.69
42	***************************	9	58	6.92	44.62
44	***************************	9	67	6.92	51.54
46	***************	5	72	3.85	55.38
48	******************	6	78	4.62	60.00
50	*********************	7	85	5.38	65.38
52	*********************	7	92	5.38	70.77
54	************************************	12	104	9.23	80.00
56	************************	8	112	6.15	86.15
58	******************************	10	122	7.69	93.85
60	************	4	126	3.08	96.92
62	*********	3	129	2.31	99.23
64		0	129	0.00	99.23
66		0	129	0.00	99.23
68	***	1	130	0.77	100.00
70		0	130	0.00	100.00
72		0	130	0.00	100.00
74		0	130	0.00	100.00
76		0	130	0.00	100.00

```
----+---+---+---+---+---+---+---+---+-
    1   2   3   4   5   6   7   8   9
```

Figure C9. Quadrula pustulosa collected at UMR mile 450.4, July 1990

LOC=806 SPECIES=QUADRULA QUADRULA

PERCENTAGE OF SHELLEN

SHELLEN		FREQ	CUM FREQ	PERCENT	CUM PERCENT
12		0	0	0.00	0.00
14		0	0	0.00	0.00
16		0	0	0.00	0.00
18		0	0	0.00	0.00
20		0	0	0.00	0.00
22	******	1	1	3.12	3.12
24		0	1	0.00	3.12
26		0	1	0.00	3.12
28	******	1	2	3.12	6.25
30	*************	2	4	6.25	12.50
32		0	4	0.00	12.50
34		0	4	0.00	12.50
36		0	4	0.00	12.50
38		0	4	0.00	12.50
40	******	1	5	3.12	15.63
42		0	5	0.00	15.63
44	*************	2	7	6.25	21.87
46		0	7	0.00	21.87
48		0	7	0.00	21.87
50		0	7	0.00	21.87
52	*************************	4	11	12.50	34.38
54		0	11	0.00	34.38
56	*******************	3	14	9.38	43.75
58	******	1	15	3.12	46.88
60	*************	2	17	6.25	53.13
62	******	1	18	3.12	56.25
64	*************	2	20	6.25	62.50
66	******	1	21	3.12	65.62
68	*******************	3	24	9.38	75.00
70	*******************	3	27	9.38	84.37
72		0	27	0.00	84.37
74		0	27	0.00	84.37
76	*************	2	29	6.25	90.62
78	******	1	30	3.12	93.75
80	******	1	31	3.12	96.87
82		0	31	0.00	96.87
84		0	31	0.00	96.87
86		0	31	0.00	96.87
88		0	31	0.00	96.87
90	******	1	32	3.12	100.00
92		0	32	0.00	100.00
94		0	32	0.00	100.00
96		0	32	0.00	100.00
98		0	32	0.00	100.00
100		0	32	0.00	100.00

----+---+---+---+---+---+-
2 4 6 8 10 12

Figure C10. Quadrula quadrula collected at UMR mile 450.4, July 1990

-------------------- LOC=807 SPECIES=QUADRULA QUADRULA --------------------

PERCENTAGE OF SHELLEN

SHELLEN		FREQ	CUM FREQ	PERCENT	CUM PERCENT
20		0	0	0.00	0.00
22		0	0	0.00	0.00
24	*****	1	1	2.56	2.56
26	*****	1	2	2.56	5.13
28		0	2	0.00	5.13
30	*****	1	3	2.56	7.69
32	*****	1	4	2.56	10.26
34		0	4	0.00	10.26
36		0	4	0.00	10.26
38		0	4	0.00	10.26
40	*****	1	5	2.56	12.82
42	*****	1	6	2.56	15.38
44	*****	1	7	2.56	17.95
46	*****	1	8	2.56	20.51
48	********************	4	12	10.26	30.77
50		0	12	0.00	30.77
52		0	12	0.00	30.77
54		0	12	0.00	30.77
56	**********	2	14	5.13	35.90
58	**********	2	16	5.13	41.03
60	*************************	5	21	12.82	53.85
62	********************	4	25	10.26	64.10
64		0	25	0.00	64.10
66		0	25	0.00	64.10
68		0	25	0.00	64.10
70	**********	2	27	5.13	69.23
72	***************	3	30	7.69	76.92
74	**********	2	32	5.13	82.05
76	*****	1	33	2.56	84.62
78	**********	2	35	5.13	89.74
80		0	35	0.00	89.74
82	***************	3	38	7.69	97.44
84		0	38	0.00	97.44
86	*****	1	39	2.56	100.00
88		0	39	0.00	100.00
90		0	39	0.00	100.00
92		0	39	0.00	100.00

----+---+---+---+---+---+--
2 4 6 8 10 12

Figure C11. _Quadrula quadrula_ collected at UMR mile 571.5, July 1990

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----------------- LOC=806 SPECIES=TRUNCILLA DONACIFORMIS -------------------

                          PERCENTAGE OF SHELLEN

SHELLEN                                         CUM                  CUM
                                         FREQ   FREQ   PERCENT   PERCENT
         |
   0     |                                  0      0      0.00      0.00
   2     |                                  0      0      0.00      0.00
   4     |                                  0      0      0.00      0.00
   6     |                                  0      0      0.00      0.00
   8     |                                  0      0      0.00      0.00
  10     |**                                1      1      2.00      2.00
  12     |**                                1      2      2.00      4.00
  14     |******                            3      5      6.00     10.00
  16     |******************                9     14     18.00     28.00
  18     |************                      6     20     12.00     40.00
  20     |**********************           11     31     22.00     62.00
  22     |************                      6     37     12.00     74.00
  24     |**********                        5     42     10.00     84.00
  26     |**********                        5     47     10.00     94.00
  28     |******                            3     50      6.00    100.00
  30     |                                  0     50      0.00    100.00
  32     |                                  0     50      0.00    100.00
  34     |                                  0     50      0.00    100.00
  36     |                                  0     50      0.00    100.00
  38     |                                  0     50      0.00    100.00
  40     |                                  0     50      0.00    100.00
          -----+----+----+----+--
               5   10   15   20
```

Figure C12. _Truncilla_ _donaciformis_ collected at UMR mile 450.4, July 1990

------------------- LOC=806 SPECIES=TRUNCILLA TRUNCATA -------------------

PERCENTAGE OF SHELLEN

SHELLEN		FREQ	CUM FREQ	PERCENT	CUM PERCENT
12		0	0	0.00	0.00
14		0	0	0.00	0.00
16		0	0	0.00	0.00
18		0	0	0.00	0.00
20		0	0	0.00	0.00
22		0	0	0.00	0.00
24	**	2	2	1.23	1.23
26	***********	9	11	5.52	6.75
28	*********	7	18	4.29	11.04
30	*************************	20	38	12.27	23.31
32	****************************	23	61	14.11	37.42
34	**********************************	28	89	17.18	54.60
36	*******************************	25	114	15.34	69.94
38	***********************	19	133	11.66	81.60
40	*************************	20	153	12.27	93.87
42	*******	6	159	3.68	97.55
44	*	1	160	0.61	98.16
46	**	2	162	1.23	99.39
48		0	162	0.00	99.39
50		0	162	0.00	99.39
52		0	162	0.00	99.39
54		0	162	0.00	99.39
56		0	162	0.00	99.39
58		0	162	0.00	99.39
60		0	162	0.00	99.39
62		0	162	0.00	99.39
64		0	162	0.00	99.39
66		0	162	0.00	99.39
68		0	162	0.00	99.39
70		0	162	0.00	99.39
72		0	162	0.00	99.39
74		0	162	0.00	99.39
76	*	1	163	0.61	100.00
78		0	163	0.00	100.00
	2 4 6 8 10 12 14 16				

Figure C13. Truncilla truncata collected at UMR mile 450.4, July 1990

SHELLEN		FREQ	CUM FREQ	PERCENT	CUM PERCENT
9		0	0	0.00	0.00
12	*****	1	1	2.38	2.38
15		0	1	0.00	2.38
18		0	1	0.00	2.38
21		0	1	0.00	2.38
24		0	1	0.00	2.38
27		0	1	0.00	2.38
30		0	1	0.00	2.38
33		0	1	0.00	2.38
36	*****	1	2	2.38	4.76
39		0	2	0.00	4.76
42		0	2	0.00	4.76
45		0	2	0.00	4.76
48	*****	1	3	2.38	7.14
51	*****	1	4	2.38	9.52
54	**************	3	7	7.14	16.67
57	**************	3	10	7.14	23.81
60	*******************	4	14	9.52	33.33
63	**********	2	16	4.76	38.10
66	***********************	5	21	11.90	50.00
69	**************	3	24	7.14	57.14
72	**************	3	27	7.14	64.29
75	*****	1	28	2.38	66.67
78	*****	1	29	2.38	69.05
81	**********	2	31	4.76	73.81
84	*****	1	32	2.38	76.19
87	**************	3	35	7.14	83.33
90	*******************	4	39	9.52	92.86
93		0	39	0.00	92.86
96		0	39	0.00	92.86
99	*****	1	40	2.38	95.24
102		0	40	0.00	95.24
105	*****	1	41	2.38	97.62
108		0	41	0.00	97.62
111		0	41	0.00	97.62
114		0	41	0.00	97.62
117	*****	1	42	2.38	100.00
120		0	42	0.00	100.00

```
----+---+---+---+---+---+--
    2   4   6   8   10  12
```

Percentage

Figure C14. Shell length frequency histogram of *Amblema plicata* at UMR mile 450.4, Pool 17, 25 July 1988 (from Miller et al. 1990).

```
SHELLEN                                                           CUM                CUM
                                                         FREQ    FREQ   PERCENT    PERCENT

   0   |                                                    0       0      0.00       0.00
   4   |                                                    0       0      0.00       0.00
   8   |                                                    0       0      0.00       0.00
  12   |                                                    0       0      0.00       0.00
  16   |                                                    0       0      0.00       0.00
  20   |                                                    0       0      0.00       0.00
  24   |***************************                        14      14     26.92      26.92
  28   |***********************************                18      32     34.62      61.54
  32   |******                                              3      35      5.77      67.31
  36   |****                                                2      37      3.85      71.15
  40   |**********                                          5      42      9.62      80.77
  44   |****                                                2      44      3.85      84.62
  48   |******                                              3      47      5.77      90.38
  52   |****                                                2      49      3.85      94.23
  56   |**                                                  1      50      1.92      96.15
  60   |                                                    0      50      0.00      96.15
  64   |****                                                2      52      3.85     100.00
  68   |                                                    0      52      0.00     100.00
  72   |                                                    0      52      0.00     100.00
        -----+----+----+----+----+----+----+-
             5   10   15   20   25   30   35

                    Percentage
```

Figure C15. Shell length frequency histogram pf *Ellipsaria lineolata* at UMR mile 450.4, Pool 17, 25 July 1988 (from Miller et al. 1990).

APPENDIX D: SUMMARY STATISTICS FOR WATER VELOCITY DATA COLLECTED IN THE UPPER MISSISSIPPI RIVER (UMR), JULY 1990

Table D1

Summary Statistics for an Increment of Water Velocity Data (Typically 100 or 200 Seconds) During and Immediately Before or After Passage of Commercial Vessel

	Y	X	Combined Velocity	Flow Direction
	9 July 1990 - File A901901			
Sensor 942 - Test 1				
Mean	2.032	0.414	1.932	180.800
SD	0.178	0.118	0.169	3.047
Min	1.691	0.155	1.600	173.200
Max	2.370	0.691	2.225	187.200
Range	0.679	0.536	0.625	14.000
N	200.	200.	200.	200.
Seconds: 50-249				
Sensor 946 - Test 1				
Mean	2.011	-0.228	2.027	155.175
SD	0.216	0.118	0.211	3.550
Min	1.537	-0.518	1.557	146.500
Max	2.392	0.017	2.397	162.200
Range	0.855	0.535	0.840	15.700
N	200.	200.	200.	200.
Seconds: 50-249				
	9 July 1990 - File B901901			
Sensor 939 - Test 1				
Mean	1.956	0.273	1.976	176.471
SD	0.163	0.066	0.163	1.904
Min	1.580	0.146	1.601	172.800
Max	2.376	0.448	2.395	182.000
Range	0.796	0.302	0.794	9.200
N	200.	200.	200.	200.
Seconds: 50-249				

(Continued)

(Sheet 1 of 41)

Table D1 (Continued)

	Y	X	Combined Velocity	Flow Direction
Sensor 940 - Test 1				
Mean	0.710	-1.190	1.399	177.305
SD	0.185	0.122	0.108	8.011
Min	0.378	-1.520	1.157	162.000
Max	1.162	-0.989	1.656	193.700
Range	0.784	0.531	0.499	31.700
N	200	200	200	200
Seconds: 50-249				
9 July 1990 - File A901902				
Sensor 942 - Before Test 2				
Mean	2.106	0.353	1.989	179.193
SD	0.193	0.087	0.176	2.536
Min	1.776	0.097	1.686	172.200
Max	2.502	0.463	2.345	182.500
Range	0.726	0.367	0.659	10.300
N	100	100	100	100
Seconds: 23-122				
Sensor 946 - Before Test 2				
Mean	1.971	-0.252	1.989	179.193
SD	0.138	0.090	0.176	2.536
Min	1.672	-0.431	1.686	172.200
Max	2.272	0.063	2.345	182.500
Range	0.600	0.494	0.659	10.300
N	100	100	100	100
Seconds: 23-122				
9 July 1990 - File A901902				
Sensor 942 - During Test 2				
Mean	2.140	0.325	2.017	178.202
SD	0.209	0.124	0.198	3.075
Min	1.702	0.038	1.594	170.700
Max	2.546	0.630	2.391	184.800
Range	0.844	0.592	0.797	14.100
N	200	200	200	200
Seconds: 123-322				

(Continued)

(Sheet 2 of 41)

Table D1 (Continued)

	Y	X	Combined Velocity	Flow Direction
Sensor 946 - During Test 2				
Mean	2.005	-0.154	2.012	157.475
SD	0.275	0.106	0.279	2.791
Min	1.517	-0.414	1.525	151.700
Max	2.519	0.055	2.530	184.800
Range	1.002	0.469	1.005	33.100
N	200	200	200	200
Seconds: 123-322				
9 July 1990 - File B901902				
Sensor 939 - Before Test 2				
Mean	2.007	0.291	2.030	176.907
SD	0.202	0.067	0.197	2.287
Min	1.669	0.139	1.703	172.600
Max	2.403	0.438	2.410	181.100
Range	0.734	0.299	0.707	8.500
N	100	100	100	100
Seconds: 23-122				
Sensor 940 - Before Test 2				
Mean	0.511	-1.422	1.518	167.656
SD	0.103	0.218	0.192	5.611
Min	0.312	-1.865	1.191	157.300
Max	0.823	-1.029	1.906	178.900
Range	0.511	0.836	0.715	21.600
N	100	100	100	100
Seconds: 23-122				
Sensor 939 - During Test 2				
Mean	1.953	0.272	1.974	176.686
SD	0.257	0.087	0.251	2.931
Min	1.460	0.080	1.489	170.400
Max	2.443	0.425	2.444	181.600
Range	0.983	0.345	0.955	11.200
N	200	200	200	200
Seconds: 123-322				

(Continued)

Table D1 (Continued)

	Y	X	Combined Velocity	Flow Direction
Sensor 940 - During Test 2				
Mean	0.543	-1.275	1.396	170.949
SD	0.131	0.225	0.199	7.191
Min	0.262	-1.704	1.019	158.100
Max	0.807	-0.830	1.780	191.300
Range	0.545	0.874	0.761	33.200
N	200	200	200	200
Seconds: 123-322				

10 July 1990 - File A901911

	Y	X	Combined Velocity	Flow Direction
Sensor 942 - Before Test 3				
Mean	1.335	0.322	1.288	171.704
SD	0.219	0.212	0.231	7.516
Min	0.964	-0.774	0.898	159.400
Max	1.816	0.034	1.722	186.300
Range	0.851	0.808	0.824	26.900
N	200	200	200	200
Seconds: 50-249				
Sensor 946 - Before Test 3				
Mean	1.751	0.855	1.952	187.665
SD	0.252	0.176	0.281	3.685
Min	1.344	0.568	1.516	178.700
Max	2.463	1.280	2.750	194.400
Range	1.119	0.712	1.234	15.700
N	200	200	200	200
Seconds: 50-249				
Sensor 942 - During Test 3				
Mean	1.570	-0.452	1.539	168.170
SD	0.254	0.254	0.230	8.895
Min	1.097	-0.927	1.054	154.900
Max	2.101	0.061	1.955	186.700
Range	1.004	0.988	0.901	31.800
N	200	200	200	200
Seconds: 293-492				

(Continued)

(Sheet 4 of 41)

Table D1 (Continued)

	Y	X	Combined Velocity	Flow Direction
Sensor 946 - During Test 3				
Mean	2.002	0.999	2.243	188.240
SD	0.329	0.212	0.358	3.992
Min	1.217	0.675	1.432	179.700
Max	2.707	1.400	2.867	195.500
Range	1.490	0.725	1.435	15.800
N	200	200	200	200
Seconds: 50-249				

10 July 1990 - File B901911

	Y	X	Combined Velocity	Flow Direction
Sensor 939 - Before Test 3				
Mean	1.721	-0.036	1.725	185.472
SD	0.227	0.116	0.227	3.894
Min	1.262	-0.337	1.262	176.500
Max	2.162	0.193	2.172	194.200
Range	0.900	0.530	0.910	17.700
N	200	200	200	200
Seconds: 50-249				
Sensor 940 - Before Test 3				
Mean	1.354	-1.524	2.042	176.571
SD	0.233	0.144	0.245	3.406
Min	0.960	-1.870	1.629	168.100
Max	1.853	-1.209	2.609	184.900
Range	0.893	0.661	0.980	16.800
N	200	200	200	200
Seconds: 50-249				
Sensor 939 - During Test 3				
Mean	2.059	-0.027	2.063	186.045
SD	0.353	0.123	0.352	3.666
Min	1.401	-0.296	1.412	178.700
Max	2.776	0.272	2.776	195.700
Range	1.375	0.568	1.364	17.000
N	200	200	200	200
Seconds: 293-492				

(Continued)

(Sheet 5 of 41)

Table D1 (Continued)

	Y	X	Combined Velocity	Flow Direction
Sensor 940 - During Test 3				
Mean	1.555	-1.556	2.208	180.782
SD	0.250	0.281	0.326	5.347
Min	0.804	-2.145	1.499	165.800
Max	2.006	-0.920	2.908	191.100
Range	1.202	1.225	1.409	25.300
N	200	200	200	200
Seconds: 293-492				
10 July 1990 - File A901912				
Sensor 942 - During Test 4				
Mean	1.242	-0.331	1.299	174.389
SD	0.153	0.189	0.153	8.354
Min	0.970	-0.675	1.028	159.000
Max	1.559	-0.022	1.647	188.500
Range	0.589	0.654	0.619	29.500
N	200	200	200	200
Seconds: 12-211				
Sensor 946 - During Test 4				
Mean	1.719	0.843	1.916	187.938
SD	0.214	0.131	0.234	2.701
Min	1.270	0.568	1.423	181.900
Max	2.209	1.253	2.415	194.400
Range	0.939	0.685	0.992	12.500
N	200	200	200	200
Seconds: 12-211				
Sensor 942 - After Test 4				
Mean	1.081	-0.440	1.187	166.876
SD	0.212	0.169	0.163	10.925
Min	0.718	-0.843	0.931	140.400
Max	1.543	-0.233	1.656	178.800
Range	0.825	0.610	0.725	38.400
N	100	100	100	100
Seconds: 460-559				

(Continued)

(Sheet 6 of 41)

Table D1 (Continued)

	Y	X	Combined Velocity	Flow Direction
Sensor 946 - After Test 4				
Mean	1.914	0.827	2.090	184.987
SD	0.096	0.190	0.155	4.021
Min	1.734	0.538	1.852	177.500
Max	2.092	1.150	2.382	190.900
Range	0.358	0.612	0.530	13.400
N	100	100	100	100
Seconds: 460-559				

10 July 1990 - File B901912

	Y	X	Combined Velocity	Flow Direction
Sensor 939 - During Test 4				
Mean	1.786	-0.003	1.788	186.216
SD	0.238	0.086	0.238	2.701
Min	1.381	-0.252	1.381	-0.252
Max	2.424	0.219	2.424	0.219
Range	1.043	0.471	1.043	0.471
N	200	200	200	200
Seconds: 12-211				
Sensor 940 - During Test 4				
Mean	1.115	-1.749	2.090	167.481
SD	0.268	0.216	0.233	7.273
Min	0.505	-2.309	1.421	151.200
Max	1.594	-1.328	2.484	184.400
Range	1.089	0.981	1.063	33.200
N	200	200	200	200
Seconds: 12-211				

10 July 1990 - File B901912

	Y	X	Combined Velocity	Flow Direction
Sensor 939 - After Test 4				
Mean	1.949	-0.091	1.952	183.617
SD	0.132	0.073	0.133	2.079
Min	1.667	-0.226	1.670	180.400
Max	2.291	0.106	2.297	189.200
Range	0.624	0.332	0.627	8.800
N	100	100	100	100
Seconds: 460-559				

(Continued)

(Sheet 7 of 41)

Table D1 (Continued)

	Y	X	Combined Velocity	Flow Direction
Sensor 940 - After Test 4				
Mean	1.273	-1.874	2.267	169.668
SD	0.176	0.219	0.263	2.616
Min	0.890	-2.397	1.810	164.000
Max	1.517	-1.540	2.821	175.800
Range	0.627	0.857	1.011	11.800
N	100	100	100	100
Seconds: 460-559				

10 July 1990 - File A901913

	Y	X	Combined Velocity	Flow Direction
Sensor 942 - Before Test 5				
Mean	1.177	-0.389	1.244	174.241
SD	0.116	0.116	0.126	4.906
Min	0.985	-0.592	1.049	164.200
Max	1.414	-0.104	1.526	186.800
Range	0.429	0.488	0.477	22.600
N	100	100	100	100
Seconds: 10-109				
Sensor 946 - Before Test 5				
Mean	1.616	0.741	1.782	186.496
SD	0.256	0.111	0.254	3.869
Min	1.203	0.528	1.395	179.400
Max	2.015	0.929	2.218	193.800
Range	0.812	0.401	0.823	14.400
N	100	100	100	100
Seconds: 10-109				
Sensor 942 - During Test 5				
Mean	1.425	-0.395	1.484	176.622
SD	0.177	0.106	0.161	5.027
Min	1.060	-0.589	1.191	164.200
Max	1.925	-0.144	1.946	187.100
Range	0.865	0.445	0.755	22.900
N	200	200	200	200
Seconds: 112-311				

(Continued)

Table D1 (Continued)

	Y	X	Combined Velocity	Flow Direction
Sensor 946 - During Test 5				
Mean	1.727	0.810	1.910	186.732
SD	0.178	0.142	0.208	2.688
Min	1.350	0.595	1.515	182.000
Max	2.199	1.290	2.413	194.400
Range	0.849	0.695	0.898	12.400
N	200	200	200	200
Seconds: 112-311				
10 July 1990 - File B901913				
Sensor 939 - Before Test 5				
Mean	1.582	0.001	1.585	185.865
SD	0.231	0.101	0.229	3.937
Min	1.135	-0.204	1.145	179.200
Max	1.939	0.226	1.940	195.500
Range	0.804	0.430	0.795	16.300
N	100	100	100	100
Seconds: 10-109				
Sensor 940 - Before Test 5				
Mean	1.051	-1.084	1.516	178.540
SD	0.195	0.123	0.186	5.276
Min	0.574	-1.344	1.012	166.800
Max	1.341	-0.815	1.867	188.100
Range	0.767	0.529	0.855	21.300
N	100	100	100	100
Seconds: 10-109				
Sensor 939 - During Test 5				
Mean	1.784	0.007	1.788	185.954
SD	0.219	0.120	0.217	3.983
Min	1.154	-0.272	1.155	176.700
Max	2.224	0.259	2.228	194.600
Range	1.070	0.531	1.073	17.900
N	200	200	200	200
Seconds: 112-311				

(Continued)

	Y	X	Combined Velocity	Flow Direction
Sensor 940 - Before Test 5				
Mean	1.428	-1.371	1.985	180.538
SD	0.254	0.167	0.262	4.845
Min	0.876	-1.753	1.522	168.500
Max	1.896	-1.052	2.511	191.400
Range	1.020	0.701	0.989	22.900
N	200	200	200	200
Seconds: 112-311				
11 July 1990 - File A901922				
Sensor 939 - Before Test 6				
Mean	1.694	0.016	1.696	192.216
SD	0.228	0.095	0.229	3.990
Min	1.280	-0.179	1.282	184.800
Max	2.139	0.226	2.141	201.500
Range	0.859	0.405	0.859	16.700
N	100	100	100	100
Seconds: 10-109				
Sensor 940 - Before Test 6				
Mean	1.412	1.715	2.224	201.035
SD	0.220	0.297	0.351	3.332
Min	0.980	1.056	1.486	192.200
Max	1.838	2.062	2.756	206.300
Range	0.858	1.006	1.270	14.100
N	100	100	100	100
Seconds: 10-109				
Sensor 939 - During Test 6				
Mean	1.462	-0.046	1.468	189.118
SD	0.295	0.117	0.296	4.546
Min	0.784	-0.272	0.800	179.600
Max	1.866	0.272	1.868	200.000
Range	1.082	0.544	1.068	20.400
N	200	200	200	200
Seconds: 112-311				

(Continued)

Table D1 (Continued)

	Y	X	Combined Velocity	Flow Direction
Sensor 940 - During Test 6				
Mean	1.384	1.567	2.095	198.835
SD	0.191	0.246	0.281	3.817
Min	0.980	1.019	1.579	189.400
Max	1.730	1.936	2.566	208.900
Range	0.750	0.917	0.987	19.500
N	200	200	200	200
Seconds: 112-311				
11 July 1990 - File B901922				
Sensor 939 - Before Test 7				
Mean	1.682	0.019	1.684	191.723
SD	0.234	0.095	0.235	3.178
Min	1.176	-0.216	1.177	182.100
Max	2.139	0.289	2.144	199.300
Range	0.963	0.505	0.967	17.200
N	200	200	200	200
Seconds: 20-219				
Sensor 940 - Before Test 7				
Mean	1.360	1.728	2.200	201.826
SD	0.123	0.175	0.199	2.013
Min	1.076	1.303	1.690	196.200
Max	1.647	2.115	2.578	205.900
Range	0.571	0.812	0.888	9.700
N	200	200	200	200
Seconds: 20-219				
Sensor 939 - During Test 7				
Mean	2.024	-0.022	2.027	190.495
SD	0.262	0.102	0.263	2.859
Min	1.627	-0.226	1.627	184.700
Max	2.809	0.208	2.811	197.200
Range	1.182	0.434	1.184	12.500
N	200	200	200	200
Seconds: 280-479				

(Continued)

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Table D1 (Continued)

	Y	X	Combined Velocity	Flow Direction
Sensor 940 - During Test 7				
Mean	1.465	1.969	2.461	203.272
SD	0.256	0.305	0.355	4.169
Min	1.013	1.393	1.781	195.500
Max	2.218	2.515	3.261	210.200
Range	1.205	1.122	1.480	14.700
N	200	200	200	200
Seconds: 280-479				
11 July 1990 - File B901923				
Sensor 939 - Before Test 8				
Mean	1.972	0.357	2.007	192.448
SD	0.203	0.132	0.209	3.486
Min	1.518	0.027	1.543	183.000
Max	2.356	0.618	2.422	199.100
Range	0.838	0.591	0.879	16.100
N	200	200	200	200
Seconds: 25-224				
Sensor 940 - Before Test 8				
Mean	1.335	1.961	2.374	201.963
SD	0.146	0.174	0.210	2.074
Min	1.043	1.534	1.861	197.300
Max	1.670	2.437	2.875	206.100
Range	0.627	0.903	1.014	8.800
N	200	200	200	200
Seconds: 25-224				
Sensor 939 - During Test 8				
Mean	2.021	0.376	2.059	192.865
SD	0.246	0.103	0.246	2.770
Min	1.428	0.106	1.454	185.000
Max	2.427	0.608	2.448	198.900
Range	0.999	0.502	0.994	13.900
N	200	200	200	200
Seconds: 312-511				

(Continued)

Table D1 (Continued)

	Y	X	Combined Velocity	Flow Direction
Sensor 940 - During Test 8				
Mean	1.384	1.988	2.426	201.064
SD	0.175	0.314	0.334	3.136
Min	0.809	1.122	1.391	193.800
Max	1.710	2.537	3.036	208.800
Range	0.901	1.415	1.645	15.000
N	200	200	200	200
Seconds: 312-511				
11 July 1990 - File: B901924				
Sensor 939 - Before Test 9				
Mean	1.864	0.328	1.896	192.059
SD	0.177	0.124	0.187	3.233
Min	1.539	0.098	1.567	185.500
Max	2.193	0.697	2.296	200.000
Range	0.654	0.599	0.729	14.500
N	100	100	100	100
Seconds: 10-109				
Sensor 940 - Before Test 9				
Mean	1.264	2.087	2.441	203.319
SD	0.130	0.204	0.232	1.589
Min	1.039	1.715	2.005	199.700
Max	1.521	2.464	2.896	207.200
Range	0.482	0.749	0.891	7.500
N	100	100	100	100
Seconds: 10-109				
Sensor 939 - During Test 9				
Mean	1.860	0.333	1.894	192.481
SD	0.269	0.120	0.267	3.819
Min	1.322	-0.027	1.331	181.400
Max	2.434	0.624	2.467	202.000
Range	1.112	0.651	1.136	20.600
N	200	200	200	200
Seconds: 107-306				

(Continued)

(Sheet 13 of 41)

Table D1 (Continued)

	Y	X	Combined Velocity	Flow Direction
Sensor 940 - During Test 9				
Mean	1.229	1.730	2.129	199.099
SD	0.181	0.233	0.239	4.853
Min	0.674	1.308	1.686	190.000
Max	1.554	2.253	2.713	211.500
Range	0.880	0.945	1.027	21.500
N	200	200	200	200
Seconds: 107-306				
11 July 1990 - File B:901925				
Sensor 939 - Before Test 10				
Mean	2.024	0.352	2.057	190.656
SD	0.167	0.103	0.173	2.438
Min	1.607	0.149	1.627	184.700
Max	2.400	0.564	2.452	195.400
Range	0.793	0.415	0.825	10.700
N	100	100	100	100
Seconds: 10-109				
Sensor 940 - Before Test 10				
Mean	1.370	2.032	2.454	198.483
SD	0.136	0.086	0.114	2.620
Min	1.066	1.846	2.264	192.600
Max	1.666	2.217	2.670	204.600
Range	0.600	0.371	0.406	12.000
N	100	100	100	100
Seconds: 10-109				
Sensor 939 - During Test 10				
Mean	1.954	0.412	1.998	192.256
SD	0.182	0.074	0.185	1.956
Min	1.499	0.272	1.545	188.000
Max	2.327	0.571	2.377	197.200
Range	0.828	0.299	0.832	9.200
N	200	200	200	200
Seconds: 137-336				

(Continued)

(Sheet 14 of 41)

Table D1 (Continued)

	Y	X	Combined Velocity	Flow Direction
Sensor 940 - During Test 10				
Mean	1.218	1.849	2.216	198.700
SD	0.132	0.191	0.213	2.378
Min	0.986	1.447	1.753	193.000
Max	1.497	2.277	2.676	204.500
Range	0.511	0.830	0.923	11.500
N	200	200	200	200
Seconds: 137-336				

11 July 1990 - File B901926

	Y	X	Combined Velocity	Flow Direction
Sensor 939 - Before Test 11				
Mean	2.024	0.360	2.059	190.168
SD	0.234	0.149	0.248	3.464
Min	1.620	0.037	1.656	181.400
Max	2.463	0.574	2.510	195.300
Range	0.843	0.537	0.854	13.900
N	100	100	100	100
Seconds: 10-109				
Sensor 940 - Before Test 11				
Mean	1.100	1.918	2.059	190.168
SD	0.128	0.169	0.248	3.464
Min	0.863	1.507	1.656	181.400
Max	1.280	2.317	2.510	195.300
Range	0.417	0.810	0.854	13.900
N	100	100	100	100
Seconds: 10-109				
Sensor 939 - During Test 11				
Mean	1.951	0.452	2.005	193.379
SD	0.242	0.101	0.245	2.799
Min	1.585	0.153	1.621	185.500
Max	2.616	0.667	2.672	200.100
Range	1.031	0.514	1.051	14.600
N	200	200	200	200
Seconds: 137-336				

(Continued)

Table D1 (Continued)

	Y	X	Combined Velocity	Flow Direction
Sensor 940 - During Test 11				
Mean	1.168	1.791	2.005	193.379
SD	0.220	0.210	0.245	2.799
Min	0.677	1.467	1.621	185.500
Max	1.560	2.417	2.672	200.100
Range	0.883	0.950	1.051	14.600
N	200	200	200	200
Seconds: 137-336				
15 July - File: A901961				
Sensor 942 - Before Test 12				
Mean	0.547	0.765	0.958	142.428
SD	0.174	0.232	0.226	12.086
Min	0.172	0.097	0.495	96.200
Max	0.891	1.287	1.481	157.900
Range	0.719	1.190	0.986	61.700
N	200	200	200	200
Seconds: 10-209				
Sensor 946 - Before Test 12				
Mean	1.299	0.240	1.324	90.131
SD	0.193	0.084	0.196	3.314
Min	0.916	-0.020	0.932	78.700
Max	1.758	0.428	1.782	96.500
Range	0.842	0.448	0.850	17.800
N	200	200	200	200
Seconds: 10-209				
Sensor 942 - During Test 12				
Mean	0.486	0.581	0.799	132.242
SD	0.144	0.377	0.313	21.739
Min	0.166	-0.115	0.247	74.000
Max	0.784	1.384	1.520	159.400
Range	0.618	1.499	1.273	85.400
N	200	200	200	200
Seconds: 235-434				

(Continued)

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Table D1 (Continued)

	Y	X	Combined Velocity	Flow Direction
Sensor 946 - During Test 12				
Mean	1.228	0.174	1.244	88.247
SD	0.236	0.080	0.231	4.251
Min	0.775	0.003	0.797	79.800
Max	1.678	0.388	1.692	97.900
Range	0.903	0.385	0.895	18.100
N	200	200	200	200
Seconds: 235-434				
15 July 1990 - File: B901961				
Sensor 939 - Before Test 12				
Mean	1.655	-0.027	1.658	107.498
SD	0.267	0.096	0.266	3.505
Min	1.102	-0.237	1.104	101.100
Max	2.046	0.231	2.048	116.800
Range	0.944	0.468	0.944	15.700
Count	200	200	200	200
Seconds: 10-209				
Sensor 940 - Before Test 12				
Mean	-0.001	0.000	0.002	63.020
SD	0.001	0.001	0.002	106.268
Mi	-0.008	-0.010	0.000	-88.100
Max	0.003	0.003	0.013	236.400
Range	0.011	0.013	0.013	324.500
Count	200	200	200	200
Seconds: 10-209				
Sensor 939 - During Test 12				
Mean	1.289	0.061	1.297	111.469
SD	0.261	0.119	0.259	5.654
Min	0.744	-0.236	0.765	98.700
Max	2.052	0.312	2.054	122.600
Range	1.308	0.548	1.289	23.900
Count	200	200	200	200
Seconds: 235-434				

(Continued)

Table D1 (Continued)

	Y	X	Combined Velocity	Flow Direction
Sensor 940 - During Test 12				
Mean	0.000	-0.001	0.001	37.172
SD	0.001	0.001	0.001	104.093
Mi	-0.003	-0.003	0.000	-88.100
Max	0.003	0.003	0.004	236.400
Range	0.006	0.006	0.004	324.500
Count	200	200	200	200
Seconds: 235-434				
15 July 1990 - File: A901962				
Sensor 942 - During Test 13				
Mean	0.610	0.890	1.091	143.082
SD	0.164	0.229	0.228	9.735
Min	0.201	0.273	0.617	109.400
Max	1.089	1.290	1.609	163.200
Range	0.888	1.017	0.992	53.800
N	200	200	200	200
Seconds: 60-259				
Sensor 946 - During Test 13				
Mean	1.363	0.293	1.396	91.810
SD	0.194	0.066	0.194	2.683
Min	1.036	0.134	1.056	86.600
Max	1.738	0.468	1.755	98.900
Range	0.702	0.334	0.699	12.300
N	200	200	200	200
Seconds: 60-259				
Sensor 942 - After Test 13				
Mean	0.492	0.361	0.662	118.043
SD	0.111	0.303	0.197	5.471
Min	0.239	-0.217	0.275	58.600
Max	0.693	0.862	1.074	155.900
Range	0.455	1.079	0.799	97.300
N	100	100	100	100
Seconds: 300-399				

(Continued)

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Table D1 (Continued)

	Y	X	Combined Velocity	Flow Direction
Sensor 946 - After Test 13				
Mean	1.407	0.303	1.441	91.865
SD	0.141	0.073	0.138	3.167
Min	1.196	0.187	1.217	86.000
Max	1.738	0.448	1.750	98.600
Range	0.542	0.261	0.533	12.600
N	100	100	100	100
Seconds: 300-399				
15 July 1990 - File B901962				
Sensor 939 - During Test 13				
Mean	1.716	-0.029	1.718	106.917
SD	0.227	0.096	0.228	3.185
Min	1.292	-0.226	1.293	100.300
Max	2.284	0.226	2.292	115.200
Range	0.992	0.452	0.999	14.900
N	200	200	200	200
Seconds: 60-259				
Sensor 940 - During Test 13				
Mean	1.800	-0.170	1.811	120.045
SD	0.210	0.098	0.209	3.073
Min	1.285	-0.375	1.290	112.400
Max	2.201	0.071	2.202	127.600
Range	0.916	0.446	0.912	15.200
N	200	200	200	200
Seconds: 60-259				
Sensor 939 - After Test 13				
Mean	1.742	0.009	1.745	108.007
SD	0.210	0.109	0.209	3.641
Min	1.391	-0.232	1.392	100.600
Max	2.142	0.259	2.146	117.400
Range	0.751	0.491	0.754	16.800
N	100	100	100	100
Seconds: 300-399				

(Continued)

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Table D1 (Continued)

	Y	X	Combined Velocity	Flow Direction
Sensor 940 - After Test 13				
Mean	1.653	-0.179	1.663	120.178
SD	0.163	0.061	0.161	2.255
Min	1.361	-0.276	1.363	116.900
Max	1.989	-0.027	1.991	125.800
Range	0.628	0.249	0.628	8.900
N	100	100	100	100
Seconds: 300-399				
15 July 1990 - File: A901963				
Sensor 942 - Before Test 14				
Mean	0.423	0.662	0.801	146.159
SD	0.209	0.193	0.238	1.027
Min	0.091	0.309	0.372	117.700
Max	1.114	1.135	1.332	166.700
Range	1.022	0.827	0.960	49.000
N	200	200	200	200
Seconds: 10-209				
Sensor 946 - Before Test 14				
Mean	1.218	0.233	1.243	90.366
SD	0.141	0.103	0.147	4.312
Min	0.862	0.003	0.893	79.700
Max	1.537	0.515	1.585	101.100
Range	0.675	0.512	0.692	21.400
N	200	200	200	200
Seconds: 10-209				
Sensor 942 - During Test 14				
Mean	0.562	0.786	0.980	141.797
SD	0.202	0.269	0.295	10.619
Min	0.144	0.219	0.406	111.800
Max	1.042	1.387	1.646	167.900
Range	0.898	1.167	1.240	56.100
N	200	200	200	200
Seconds: 225-424				

(Continued)

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Table D1 (Continued)

	Y	X	Combined Velocity	Flow Direction
Sensor 946 - During Test 14				
Mean	1.303	0.276	1.335	91.574
SD	0.172	0.103	0.176	4.033
Min	0.909	0.104	0.931	83.800
Max	1.567	0.535	1.604	100.500
Range	0.658	0.431	0.673	16.700
N	200	200	200	200
Seconds: 225-424				

15 July 1990 - File: B901963

	Y	X	Combined Velocity	Flow Direction
Sensor 939 Before Test 14				
Mean	1.596	0.007	1.599	107.691
SD	0.280	0.090	0.281	3.081
Min	1.132	-0.244	1.137	99.600
Max	2.161	0.224	2.170	113.400
Range	1.029	0.468	1.033	13.800
N	200	200	200	200
Seconds: 10-209				
Sensor 940 Before Test 14				
Mean	1.937	-0.302	1.965	118.271
SD	0.138	0.139	0.137	3.969
Min	1.644	-0.554	1.657	112.600
Max	2.235	0.050	2.286	128.500
Range	0.591	0.604	0.629	15.900
N	200	200	200	200
Seconds: 10-209				
Sensor 939 - During Test 14				
Mean	1.667	-0.032	1.671	106.233
SD	0.203	0.105	0.203	3.570
Min	1.330	-0.276	1.335	99.000
Max	2.244	0.188	2.245	114.000
Range	0.914	0.464	0.910	15.000
N	200	200	200	200
Seconds: 218-417				

(Continued)

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Table D1 (Continued)

	Y	X	Combined Velocity	Flow Direction
Sensor 940 - During Test 14				
Mean	1.847	-0.215	1.862	120.410
SD	0.173	0.095	0.173	2.895
Min	1.451	-0.412	1.458	113.600
Max	2.263	-0.010	2.266	126.400
Range	0.812	0.402	0.808	12.800
N	200	200	200	200
Seconds: 218-417				
15 July 1990 - File: A901964				
Sensor 942 - Before Test 15				
Mean	0.424	0.622	0.781	142.692
SD	0.160	0.239	0.198	16.250
Min	0.137	0.022	0.380	90.200
Max	0.930	1.133	1.194	165.200
Range	0.793	1.112	0.814	75.000
Count	200	200	200	200
Seconds: 10-209				
Sensor 946 - Before Test 15				
Mean	1.215	0.261	1.244	91.973
SD	0.168	0.050	0.164	2.925
Min	0.882	0.117	0.925	84.900
Max	1.574	0.401	1.603	98.500
Range	0.692	0.284	0.678	13.600
Count	200	200	200	200
Seconds: 10-209				
Sensor 942 - During Test 15				
Mean	0.459	0.454	0.680	130.360
SD	0.152	0.223	0.167	19.556
Min	0.126	-0.029	0.289	82.800
Max	0.871	0.804	1.023	167.800
Range	0.745	0.833	0.734	85.000
Count	200	200	200	200
Seconds: 218-417				

(Continued)

(Sheet 22 of 41)

Table D1 (Continued)

	Y	X	Combined Velocity	Flow Direction
Sensor 946 - During Test 15				
Mean	1.219	0.212	1.243	89.823
SD	0.232	0.117	0.229	5.518
Min	0.735	-0.060	0.757	77.400
Max	1.580	0.468	1.582	104.800
Range	0.845	0.528	0.825	27.400
Count	200	200	200	200
Seconds: 218-417				
15 July 1990 - File B901964				
Sensor 939 - Before Test 15				
Mean	1.625	0.097	1.633	110.942
SD	0.274	0.133	0.275	4.684
Min	1.159	-0.226	1.166	100.100
Max	2.124	0.320	2.127	118.800
Range	0.965	0.546	0.961	18.700
N	200	200	200	200
Seconds: 10-209				
Sensor 940 - Before Test 15				
Mean	1.519	-0.515	1.613	114.697
SD	0.178	0.154	0.166	3.345
Min	1.139	-0.704	1.208	109.700
Max	1.882	-0.166	1.894	123.200
Range	0.743	0.538	0.686	13.500
N	200	200	200	200
Seconds: 10-209				
Sensor 939 - During Test 15				
Mean	1.185	0.156	1.198	114.536
SD	0.205	0.085	0.208	3.836
Min	0.823	-0.043	0.835	104.900
Max	1.713	0.345	1.728	121.700
Range	0.890	0.388	0.893	16.800
N	200	200	200	200
Seconds: 218-417				

(Continued)

(Sheet 23 of 41)

Table D1 (Continued)

	Y	X	Combined Velocity	Flow Direction
Sensor 940 - During Test 15				
Mean	1.183	-0.440	1.266	114.440
SD	0.333	0.142	0.349	4.912
Min	0.642	-0.704	0.733	102.800
Max	1.793	-0.164	1.895	127.400
Range	1.151	0.540	1.162	24.600
N	200	200	200	200
Seconds: 218-417				
16 July 1990 - File: A901971				
Sensor 942 - During Test 18				
Mean	0.294	0.131	0.331	165.490
SD	0.077	0.061	0.060	13.617
Min	0.158	-0.008	0.200	138.800
Max	0.424	0.241	0.440	189.500
Range	0.266	0.248	0.240	50.700
N	200	200	200	200
Seconds: 21-220				
Sensor 946 - During Test 18				
Mean	0.214	-0.539	0.583	56.785
SD	0.083	0.112	0.125	5.933
Min	0.074	-0.715	0.331	42.300
Max	0.418	-0.297	0.800	68.700
Range	0.344	0.418	0.469	26.400
N	200	200	200	200
Seconds: 21-220				
Sensor 942 - After Test 18				
Mean	0.246	0.103	0.269	163.084
SD	0.056	0.017	0.049	7.248
Min	0.151	0.072	0.188	154.200
Max	0.324	0.137	0.341	180.100
Range	0.173	0.065	0.153	25.900
N	100	100	100	100
Seconds: 370-469				

(Continued)

(Sheet 24 of 41)

Table D1 (Continued)

	Y	X	Combined Velocity	Flow Direction
Sensor 946 - After Test 18				
Mean	0.316	-0.456	0.563	69.520
SD	0.107	0.055	0.075	9.785
Min	0.120	-0.563	0.456	49.500
Max	0.508	-0.334	0.731	81.200
Range	0.388	0.229	0.275	31.700
N	100	100	100	100
Seconds: 370-469				
16 July 1990 - File: B901971				
Sensor 940 - During Test 18				
Mean	0.931	-0.966	1.351	87.953
SD	0.268	0.203	0.298	6.901
Min	0.405	-1.322	0.776	72.600
Max	1.365	-0.591	1.776	100.600
Range	0.960	0.731	1.000	28.000
N	200	200	200	200
Seconds: 21-220				
Sensor 940 - After Test 18				
Mean	0.915	-0.929	1.308	92.159
SD	0.115	0.151	0.162	4.181
Min	0.667	-1.272	1.034	79.700
Max	1.139	-0.697	1.583	99.300
Range	0.472	0.575	0.549	19.600
N	100	100	100	100
Seconds: 370-469				
16 July 1990 - File A901972				
Sensor 942 - Before Test 19				
Mean	0.235	0.031	0.243	146.556
SD	0.057	0.051	0.055	13.394
Min	0.126	-0.228	0.149	78.100
Max	0.330	0.104	0.338	168.300
Range	0.204	0.332	0.189	90.200
N	200	200	200	200
Seconds: 10-209				

(Continued)

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Table D1 (Continued)

	Y	X	Combined Velocity	Flow Direction
Sensor 946 - Before Test 19				
Mean	0.302	-0.610	0.683	61.513
SD	0.078	0.104	0.118	4.695
Min	0.147	-0.789	0.401	53.600
Max	0.445	-0.361	0.894	76.700
Range	0.298	0.428	0.493	23.100
N	200	200	200	200
Seconds: 10-209				
Sensor 942 - During Test 19				
Mean	0.211	0.090	0.250	166.828
SD	0.095	0.069	0.066	24.668
Min	0.029	-0.003	0.137	138.600
Max	0.396	0.233	0.399	217.800
Range	0.367	0.237	0.262	79.200
N	200	200	200	200
Seconds: 266-465				
Sensor 946 - During Test 19				
Mean	0.166	-0.393	0.444	113.929
SD	0.169	0.177	0.212	117.760
Mi	-0.100	-0.709	0.038	37.300
Max	0.602	-0.037	0.835	394.300
Range	0.702	0.672	0.797	357.000
N	200	200	200	200
Seconds: 266-465				
16 July 1990 - File B901972				
Sensor 940 - Before Test 19				
Mean	1.226	-0.613	1.374	91.483
SD	0.165	0.062	0.151	3.817
Min	0.903	-0.731	1.072	83.900
Max	1.604	-0.438	1.723	98.900
Range	0.701	0.293	0.651	15.000
N	200	200	200	200
Seconds: 10-209				

(Continued)

(Sheet 26 of 41)

Table D1 (Continued)

	Y	X	Combined Velocity	Flow Direction
Sensor 940 - During Test 19				
Mean	0.799	-0.449	0.919	88.667
SD	0.210	0.108	0.224	4.604
Min	0.415	-0.697	0.469	76.700
Max	1.162	-0.203	1.289	99.300
Range	0.747	0.494	0.820	22.600
N	200	200	200	200
Seconds: 266-465				
16 July 1990 - File A1901973				
Sensor 942 - Before Test 20				
Mean	0.279	0.052	0.284	149.531
SD	0.032	0.018	0.032	3.519
Min	0.233	0.014	0.237	142.200
Max	0.345	0.094	0.348	159.500
Range	0.112	0.080	0.111	17.300
N	200	200	200	200
Seconds: 50-249				
File A2901973				
Sensor 946 - Before Test 20				
Mean	0.272	-0.513	0.585	63.094
SD	0.087	0.091	0.104	6.904
Min	0.097	-0.712	0.386	45.400
Max	0.468	-0.342	0.808	76.100
Range	0.371	0.370	0.422	30.700
N	200	200	200	200
Seconds: 50-249				
Sensor 942 - During Test 20				
Mean	0.458	-0.153	0.492	124.589
SD	0.138	0.131	0.164	13.373
Min	0.244	-0.324	0.245	111.900
Max	0.657	0.051	0.720	149.900
Range	0.413	0.374	0.475	38.000
N	200	200	200	200
Seconds: 656-855				

(Continued)

(Sheet 27 of 41)

Table D1 (Continued)

	Y	X	Combined Velocity	Flow Direction
Sensor 946 - During Test 20				
Mean	0.386	-0.845	0.933	60.500
SD	0.086	0.222	0.225	4.714
Min	0.221	-1.226	0.547	51.700
Max	0.595	-0.481	1.300	72.700
Range	0.374	0.745	0.753	21.000
N	200	200	200	200
Seconds: 656-855				
Sensor 939 - Before Test 20				
Mean	1.043	1.011	1.453	150.289
SD	0.076	0.083	0.100	2.078
Min	0.856	0.777	1.160	145.400
Max	1.251	1.155	1.607	153.900
Range	0.395	0.378	0.447	8.500
N	200	200	200	200
Seconds: 50-249				
Sensor 940 - Before Test 20				
Mean	0.999	-0.504	1.124	101.914
SD	0.145	0.069	0.126	5.057
Min	0.797	-0.704	0.926	92.100
Max	1.361	-0.365	1.436	111.000
Range	0.564	0.339	0.510	18.900
N	200	200	200	200
Seconds: 50-249				
Sensor 939 - During Test 20				
Mean	1.183	1.146	1.654	149.904
SD	0.250	0.195	0.276	5.415
Min	0.787	0.833	1.190	138.100
Max	1.714	1.507	2.146	163.700
Range	0.927	0.674	0.956	25.600
N	200	200	200	200
Seconds: 656-855				

(Continued)

Table D1 (Continued)

	Y	X	Combined Velocity	Flow Direction
Sensor 940 - During Test 20				
Mean	1.349	-0.615	1.489	104.269
SD	0.236	0.139	0.235	5.767
Min	0.783	-0.896	1.044	87.600
Max	1.759	-0.305	1.937	116.300
Range	0.976	0.591	0.893	28.700
N	200	200	200	200
Seconds: 656-855				
16 July 1990 - File A901974				
Sensor 942 - Before Test 21				
Mean	0.295	0.004	0.296	139.397
SD	0.025	0.025	0.025	4.921
Min	0.252	-0.040	0.252	131.200
Max	0.367	0.072	0.367	152.400
Range	0.115	0.112	0.115	21.200
N	200	200	200	200
Seconds: 10-209				
Sensor 946 - Before Test 21				
Mean	0.303	-0.559	0.640	63.001
SD	0.112	0.077	0.115	6.147
Min	0.147	-0.738	0.466	52.100
Max	0.618	-0.418	0.950	77.300
Range	0.471	0.320	0.484	25.200
N	200	200	200	200
Seconds: 10-209				
Sensor 942 - During Test 21				
Mean	0.257	-0.036	0.263	131.786
SD	0.032	0.044	0.035	9.498
Min	0.201	-0.101	0.203	116.500
Max	0.313	0.043	0.321	150.400
Range	0.112	0.144	0.118	33.900
N	200	200	200	200
Seconds: 214-413				

(Continued)

Table D1 (Continued)

	Y	X	Combined Velocity	Flow Direction
Sensor 946 - During Test 21				
Mean	0.301	-0.596	0.673	60.871
SD	0.144	0.160	0.198	7.303
Min	0.097	-1.002	0.364	48.200
Max	0.596	-0.321	1.152	75.300
Range	0.499	0.681	0.788	27.100
N	200	200	200	200
Seconds: 214-413				

16 July 1990 - File B901974

	Y	X	Combined Velocity	Flow Direction
Sensor 939 - Before Test 21				
Mean	1.037	0.969	1.420	149.028
SD	0.090	0.088	0.117	1.888
Min	0.863	0.777	1.161	144.400
Max	1.228	1.152	1.675	152.700
Range	0.365	0.375	0.514	8.300
N	200	200	200	200
Seconds: 10-209				
Sensor 940 - Before Test 21				
Mean	1.008	-0.583	1.168	99.259
SD	0.103	0.096	0.104	4.689
Min	0.830	-0.835	0.941	86.500
Max	1.261	-0.405	1.396	107.600
Range	0.431	0.430	0.455	21.100
N	200	200	200	200
Seconds: 10-209				
Sensor 939 - During Test 21				
Mean	1.112	1.009	1.503	147.834
SD	0.108	0.126	0.156	2.174
Min	0.885	0.747	1.163	142.300
Max	1.334	1.255	1.720	153.100
Range	0.449	0.508	0.557	10.800
N	200	200	200	200
Seconds: 214-413				

(Continued)

Table D1 (Continued)

	Y	X	Combined Velocity	Flow Direction
Sensor 940 - During Test 21				
Mean	1.009	-0.535	1.146	101.411
SD	0.108	0.103	0.119	4.461
Min	0.833	-0.830	0.924	90.700
Max	1.238	-0.358	1.463	111.600
Range	0.405	0.472	0.539	20.900
N	200	200	200	200
Seconds: 214-413				
17 July 1990 - File A901981				
Sensor 942 - Before Test 22				
Mean	0.012	0.036	0.047	210.223
SD	0.018	0.027	0.016	56.733
Mi	-0.022	-0.081	0.011	52.000
Max	0.043	0.072	0.072	398.700
Range	0.065	0.090	0.061	346.700
N	200	200	200	200
Seconds: 10-209				
Sensor 946 - Before Test 22				
Mean	0.666	-0.582	0.890	75.255
SD	0.158	0.064	0.139	6.038
Min	0.406	-0.722	0.607	65.500
Max	1.022	-0.441	1.177	89.300
Range	0.616	0.281	0.570	23.800
N	200	200	200	200
Seconds: 10-209				
Sensor 942 - During Test 22				
Mean	0.015	-0.020	0.075	192.762
SD	0.031	0.075	0.040	124.448
Mi	-0.029	-0.112	0.008	53.800
Max	0.086	0.151	0.152	409.100
Range	0.115	0.262	0.144	355.300
N	200	200	200	200
Seconds: 244-443				

(Continued)

Table D1 (Continued)

	Y	X	Combined Velocity	Flow Direction
Sensor 946 - During Test 22				
Mean	0.713	-0.576	0.928	76.938
SD	0.203	0.069	0.162	8.654
Min	0.409	-0.742	0.653	61.900
Max	1.146	-0.378	1.279	94.100
Range	0.737	0.364	0.626	32.200
N	200	200	200	200
Seconds: 244-443				
17 July 1990 - File B901981				
Sensor 939 - Before Test 22				
Mean	0.837	-0.881	1.220	85.562
SD	0.156	0.153	0.188	5.295
Min	0.524	-1.168	0.890	62.000
Max	1.139	-0.617	1.557	94.600
Range	0.615	0.551	0.667	32.600
Count	200	200	200	200
Seconds: 10-209				
Sensor 940 - Before Test 22				
Mean	1.032	-0.989	1.432	103.577
SD	0.117	0.100	0.130	3.313
Min	0.810	-1.158	1.172	93.900
Max	1.265	-0.744	1.705	110.800
Range	0.455	0.414	0.533	16.900
Count	200	200	200	200
Seconds: 10-209				
Sensor 939 - During Test 22				
Mean	0.877	-0.878	1.245	86.660
SD	0.156	0.101	0.154	4.861
Min	0.544	-1.132	0.937	76.400
Max	1.215	-0.661	1.578	96.300
Range	0.671	0.471	0.641	19.900
Count	200	200	200	200
Seconds: 244-443				

(Continued)

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Table D1 (Continued)

	Y	X	Combined Velocity	Flow Direction
Sensor 940 - During Test 22				
Mean	1.024	-0.933	1.387	104.739
SD	0.143	0.104	0.165	2.698
Min	0.730	-1.148	1.092	98.400
Max	1.344	-0.727	1.750	109.900
Range	0.614	0.421	0.658	11.500
Count	200	200	200	200
Seconds: 244-443				
17 July 1990 - File: A901982				
Sensor 942 - Before Test 23				
Mean	0.028	0.045	0.072	200.749
SD	0.042	0.029	0.017	40.646
Min	-0.051	-0.029	0.032	123.100
Max	0.104	0.094	0.106	262.100
Range	0.155	0.123	0.074	139.000
N	200	200	200	200
Seconds: 10-209				
Sensor 946 - Before Test 23				
Mean	0.749	-0.629	0.981	77.045
SD	0.104	0.083	0.108	4.572
Min	0.508	-0.782	0.733	67.300
Max	0.962	-0.438	1.164	90.100
Range	0.454	0.344	0.431	22.800
N	200	200	200	200
Seconds: 10-209				
Sensor 942 - During Test 23				
Mean	-0.004	0.095	0.199	196.609
SD	0.125	0.159	0.101	67.568
Min	-0.204	-0.158	0.032	90.100
Max	0.215	0.316	0.359	267.800
Range	0.419	0.474	0.327	177.700
N	200	200	200	200
Seconds: 236-435				

(Continued)

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Table D1 (Continued)

	Y	X	Combined Velocity	Flow Direction
Sensor 946 - During Test 23				
Mean	0.525	-0.370	0.647	80.409
SD	0.238	0.150	0.269	8.299
Min	0.124	-0.621	0.189	54.600
Max	0.852	-0.134	0.970	95.000
Range	0.728	0.487	0.781	40.400
N	200	200	200	200
Seconds: 236-435				

17 July 1990 - File B901982

	Y	X	Combined Velocity	Flow Direction
Sensor 939 - Before Test 23				
Mean	0.731	-0.835	1.111	82.780
SD	0.137	0.141	0.188	2.858
Min	0.455	-1.075	0.754	77.200
Max	1.052	-0.554	1.407	91.100
Range	0.597	0.521	0.653	13.900
N	200	200	200	200
Seconds: 10-209				
Sensor 940 - Before Test 23				
Mean	0.924	-0.947	1.325	101.698
SD	0.111	0.111	0.135	3.432
Min	0.651	-1.148	1.039	95.200
Max	1.143	-0.717	1.598	108.200
Range	0.492	0.431	0.559	13.000
N	200	200	200	200
Seconds: 10-209				
Sensor 939 - During Test 23				
Mean	0.534	-0.653	0.853	77.899
SD	0.266	0.182	0.296	9.804
Min	0.100	-0.981	0.360	57.000
Max	0.961	-0.329	1.272	93.600
Range	0.861	0.652	0.912	36.600
N	200	200	200	200
Seconds: 236-435				

(Continued)

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Table D1 (Continued)

	Y	X	Combined Velocity	Flow Direction
Sensor 940 - During Test 23				
Mean	0.741	-0.829	1.134	97.093
SD	0.326	0.209	0.317	11.875
Min	0.262	-1.155	0.582	76.700
Max	1.291	-0.438	1.630	123.800
Range	1.029	0.717	1.048	47.100
N	200	200	200	200
Seconds: 236-435				
17 July 1990 - File A901983				
Sensor 942 - Before Test 24				
Mean	-0.035	-0.016	0.045	328.207
SD	0.020	0.019	0.016	68.824
Min	-0.072	-0.043	0.014	51.500
Max	0.011	0.029	0.078	405.000
Range	0.083	0.072	0.064	353.500
N	200	200	200	200
Seconds: 10-209				
Sensor 946 - Before Test 24				
Mean	0.599	-0.504	0.785	77.135
SD	0.094	0.093	0.120	4.249
Min	0.434	-0.681	0.587	69.400
Max	0.800	-0.314	1.044	89.600
Range	0.366	0.367	0.457	20.200
N	200	200	200	200
Seconds: 10-209				
Sensor 942 - During Test 24				
Mean	0.062	-0.036	0.078	106.975
SD	0.032	0.027	0.028	22.427
Min	0.011	-0.090	0.026	70.900
Max	0.118	0.008	0.118	145.500
Range	0.108	0.098	0.092	74.600
N	200	200	200	200
Seconds: 342-541				

(Continued)

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Table D1 (Continued)

	Y	X	Combined Velocity	Flow Direction
Sensor 946 - During Test 24				
Mean	0.600	-0.469	0.765	78.798
SD	0.098	0.063	0.088	5.667
Min	0.401	-0.621	0.546	67.400
Max	0.885	-0.321	0.999	89.800
Range	0.484	0.300	0.453	22.400
N	200	200	200	200
Seconds: 342-541				
17 July 1990 - File B901983				
Sensor 939 - Before Test 24				
Mean	0.721	-0.752	1.045	86.230
SD	0.112	0.140	0.161	4.246
Min	0.518	-1.075	0.753	78.800
Max	0.929	-0.511	1.408	97.900
Range	0.411	0.564	0.655	19.100
N	200	200	200	200
Seconds: 10-209				
Sensor 940 - Before Test 24				
Mean	1.033	-0.849	1.340	107.296
SD	0.093	0.124	0.130	3.568
Min	0.856	-1.178	1.079	98.100
Max	1.211	-0.612	1.586	114.900
Range	0.355	0.566	0.507	16.800
N	200	200	200	200
Seconds: 10-209				
Sensor 939 - During Test 24				
Mean	0.722	-0.628	0.959	91.688
SD	0.076	0.122	0.126	4.126
Min	0.571	-0.956	0.766	83.000
Max	0.909	-0.441	1.291	102.600
Range	0.338	0.515	0.525	19.600
N	200	200	200	200
Seconds: 342-541				

(Continued)

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Table D1 (Continued)

	Y	X	Combined Velocity	Flow Direction
Sensor 940 - During Test 24				
Mean	1.148	-0.778	1.389	112.434
SD	0.146	0.100	0.156	3.500
Min	0.863	-1.128	1.081	104.300
Max	1.413	-0.494	1.795	120.400
Range	0.550	0.634	0.714	16.100
N	200	200	200	200
Seconds: 342-541				
21 July 1990 - File A1902021				
Sensor 942 - Before Test 25				
Mean	0.073	0.692	0.696	179.448
SD	0.020	0.048	0.408	1.591
Min	0.022	0.586	0.587	175.400
Max	0.118	0.798	0.804	183.600
Range	0.097	0.212	0.217	8.200
N	200	200	200	200
Seconds: 10-209				
Sensor 946 - Before Test 25				
Mean	0.069	0.818	0.821	156.678
SD	0.020	0.080	0.080	1.404
Min	0.017	0.612	0.615	153.200
Max	0.117	0.949	0.956	160.500
Range	0.100	0.337	0.341	7.300
N	200	200	200	200
Seconds: 10-209				
Sensor 942 - During Test 25				
Mean	0.081	0.703	0.708	179.092
SD	0.032	0.092	0.094	2.332
Min	-0.014	0.489	0.489	173.700
Max	0.158	0.827	0.832	187.100
Range	0.172	0.338	0.343	13.400
N	200	200	200	200
Seconds: 522-721				

(Continued)

(Sheet 37 of 41)

Table D1 (Continued)

	Y	X	Combined Velocity	Flow Direction
Sensor 946 - During Test 25				
Mean	0.042	0.762	0.765	158.425
SD	0.057	0.085	0.083	4.692
Min	-0.130	0.555	0.555	146.100
Max	0.167	0.903	0.909	172.500
Range	0.297	0.348	0.354	26.400
N	200	200	200	200
Seconds: 522-721				
21 July 1990 - File B1902021				
Sensor 939 - Before Test 25				
Mean	0.033	1.127	1.128	163.224
SD	0.036	0.086	0.086	1.795
Min	-0.050	0.937	0.938	158.800
Max	0.116	1.368	1.372	167.200
Range	0.166	0.431	0.434	8.400
N	200	200	200	200
Seconds: 10-209				
Sensor 940 - Before Test 25				
Mean	-0.098	0.948	0.954	185.676
SD	0.059	0.107	0.111	2.882
Min	-0.216	0.702	0.708	179.200
Max	0.015	1.149	1.161	191.300
Range	0.231	0.447	0.453	12.100
N	200	200	200	200
Seconds: 10-209				
Sensor 939 - During Test 25				
Mean	0.039	1.101	1.106	162.937
SD	0.095	0.176	1.174	5.670
Min	-0.252	0.558	0.558	151.000
Max	0.196	1.342	1.244	181.900
Range	0.448	0.784	0.786	30.900
N	200	200	200	200
Seconds: 522-721				

(Continued)

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Table D1 (Continued)

	Y	X	Combined Velocity	Flow Direction
Sensor 940 - During Test 25				
Mean	-0.135	0.875	0.902	189.162
SD	0.143	0.223	0.202	13.118
Min	-0.561	0.166	0.257	158.900
Max	0.257	1.226	1.228	238.200
Range	0.818	1.060	0.971	79.300
N	200	200	200	200
Seconds: 522-721				
21 July 1990 - File A902022				
Sensor 942 - Before Test 26				
Mean	0.074	0.650	0.654	178.681
SD	0.017	0.051	0.052	1.276
Min	0.043	0.532	0.534	175.600
Max	0.115	0.734	0.739	181.200
Range	0.072	0.202	0.205	5.600
N	100	100	100	100
Seconds: 10-109				
Sensor 946 - Before Test 26				
Mean	0.045	0.813	0.815	158.299
SD	0.030	0.047	0.047	2.068
Min	-0.003	0.695	0.697	153.700
Max	0.107	0.895	0.900	161.700
Range	0.110	0.200	0.203	8.000
N	100	100	100	100
Seconds: 10-109				
Sensor 942 - During Test 26				
Mean	0.076	0.761	0.765	179.521
SD	0.019	0.065	0.066	1.277
Min	0.029	0.643	0.645	176.700
Max	0.129	0.916	0.922	183.000
Range	0.100	0.273	0.277	6.300
N	200	200	200	200
Seconds: 234-433				

(Continued)

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Table D1 (Continued)

	Y	X	Combined Velocity	Flow Direction
Sensor 946 - During Test 26				
Mean	0.054	0.846	0.849	157.920
SD	0.043	0.108	0.108	2.802
Min	-0.040	0.648	0.648	152.400
Max	0.127	1.026	1.026	163.900
Range	0.167	0.378	0.378	11.500
N	200	200	200	200
Seconds: 234-433				
21 July 1990 - File B902022				
Sensor 939 - Before Test 26				
Mean	0.054	1.178	1.180	158.707
SD	0.036	0.078	0.078	1.803
Min	-0.040	0.981	0.982	155.400
Max	0.120	1.298	1.298	163.300
Range	0.160	0.317	0.316	7.900
C	100	100	100	100
Seconds: 10-109				
Sensor 940 - Before Test 26				
Mean	-0.056	0.902	1.180	158.707
SD	0.036	0.089	0.078	1.803
Mi	-0.166	0.747	0.982	155.400
Max	0.003	1.076	1.298	163.300
Range	0.169	0.329	0.316	7.900
C	100	100	100	100
Seconds: 10-109				
Sensor 939 - During Test 26				
Mean	0.062	1.212	1.215	158.392
SD	0.049	0.059	0.060	2.267
Min	-0.090	1.086	1.089	153.600
Max	0.173	1.341	1.343	165.500
Range	0.263	0.255	0.254	11.900
C	200	200	200	200
Seconds: 234-433				

(Continued)

(Sheet 40 of 41)

Table D1 (Concluded)

	Y	X	Combined Velocity	Flow Direction
Sensor 940 - During Test 26				
Mean	-0.078	0.948	1.215	158.392
SD	0.063	0.092	0.060	2.267
Min	-0.232	0.785	1.089	153.600
Max	0.043	1.178	1.343	165.500
Range	0.275	0.393	0.254	11.900
C	200	200	200	200
Seconds: 234-433				

(Sheet 41 of 41)

APPENDIX E: CHANGES IN WATER VELOCITY ASSOCIATED WITH VESSEL PASSAGES IN THE UPPER MISSISSIPPI RIVER (UMR), JULY 1990

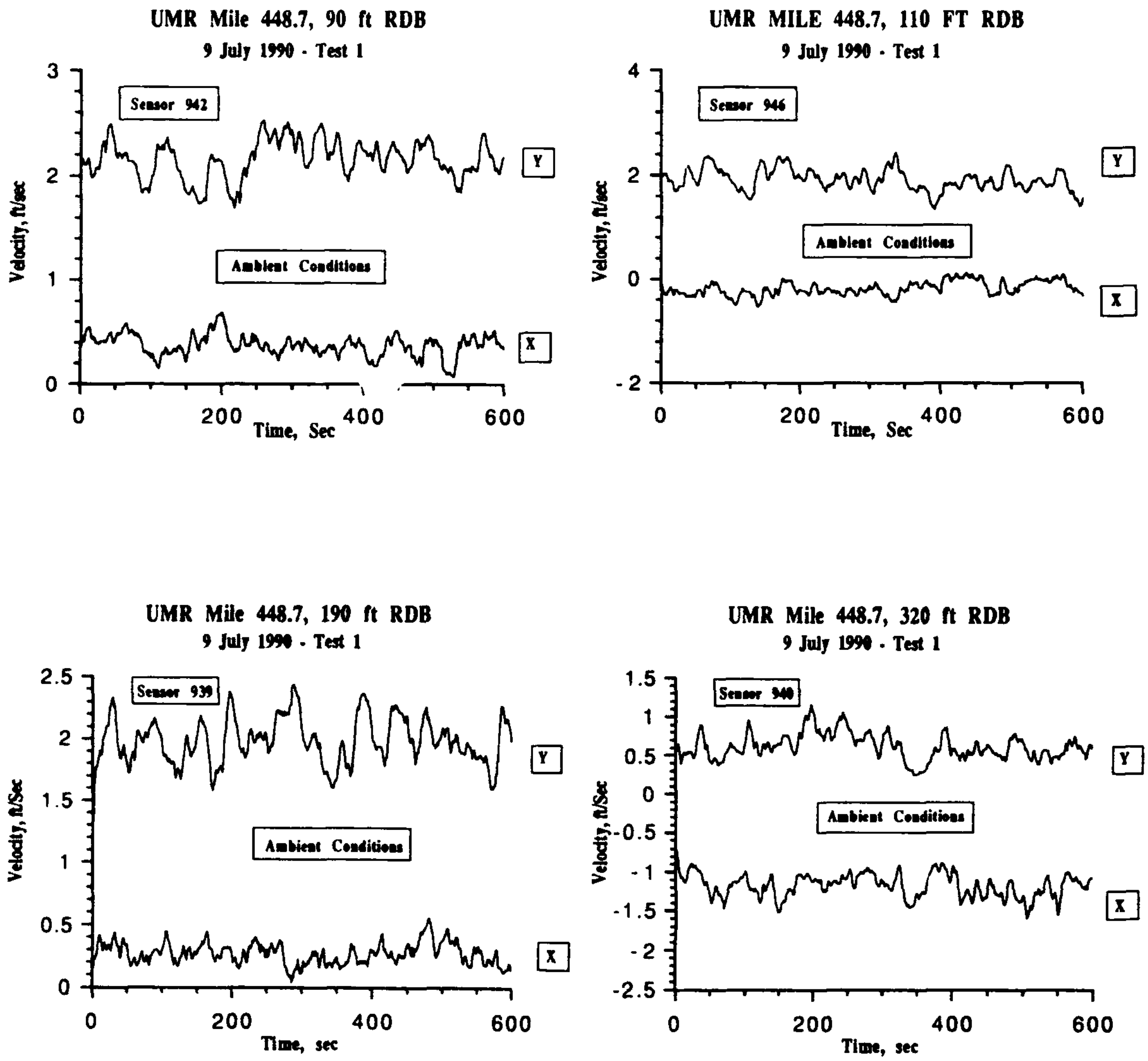

UMR Mile 448.7, 90 ft RDB
9 July 1990 - Test 1
Sensor 942
Ambient Conditions
Y
X
Velocity, ft/sec
Time, Sec
UMR MILE 448.7, 110 FT RDB
9 July 1990 - Test 1
Sensor 946
Ambient Conditions
Y
X
Velocity, ft/sec
Time, Sec
UMR Mile 448.7, 190 ft RDB
9 July 1990 - Test 1
Sensor 939
Ambient Conditions
Y
X
Velocity, ft/Sec
Time, sec
UMR Mile 448.7, 320 ft RDB
9 July 1990 - Test 1
Sensor 940
Ambient Conditions
Y
X
Velocity, ft/Sec
Time, sec

Figure E1

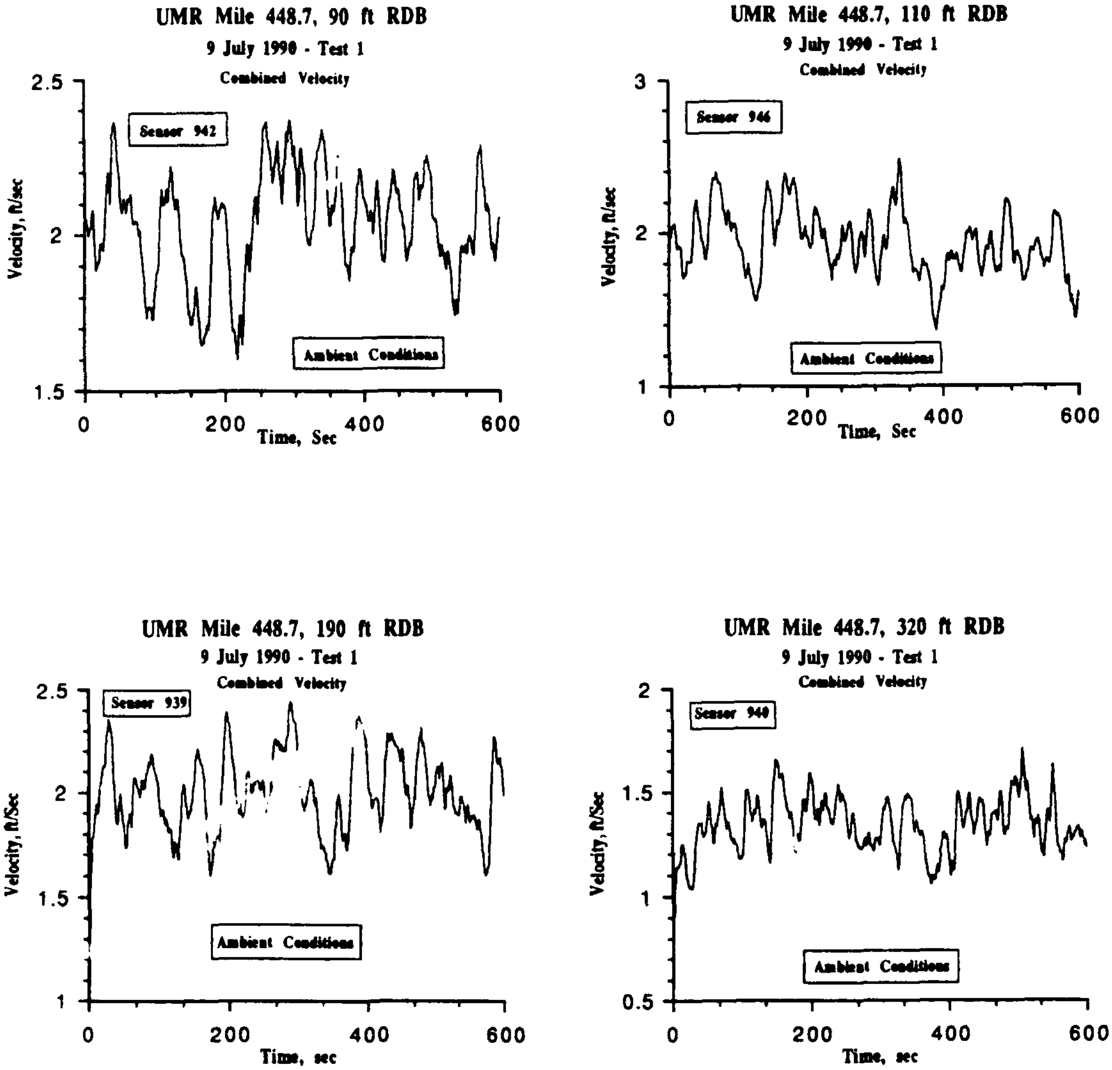

UMR Mile 448.7, 90 ft RDB
9 July 1990 - Test 1
Combined Velocity
Sensor 942
Ambient Conditions
Velocity, ft/sec
Time, Sec
2.5
2
1.5
0
200
400
600
UMR Mile 448.7, 110 ft RDB
9 July 1990 - Test 1
Combined Velocity
Sensor 946
Ambient Conditions
Velocity, ft/sec
Time, Sec
3
2
1
0
200
400
600
UMR Mile 448.7, 190 ft RDB
9 July 1990 - Test 1
Combined Velocity
Sensor 939
Ambient Conditions
Velocity, ft/Sec
Time, sec
2.5
2
1.5
1
0
200
400
600
UMR Mile 448.7, 320 ft RDB
9 July 1990 - Test 1
Combined Velocity
Sensor 940
Ambient Conditions
Velocity, ft/Sec
Time, sec
2
1.5
1
0.5
0
200
400
600

Figure E2

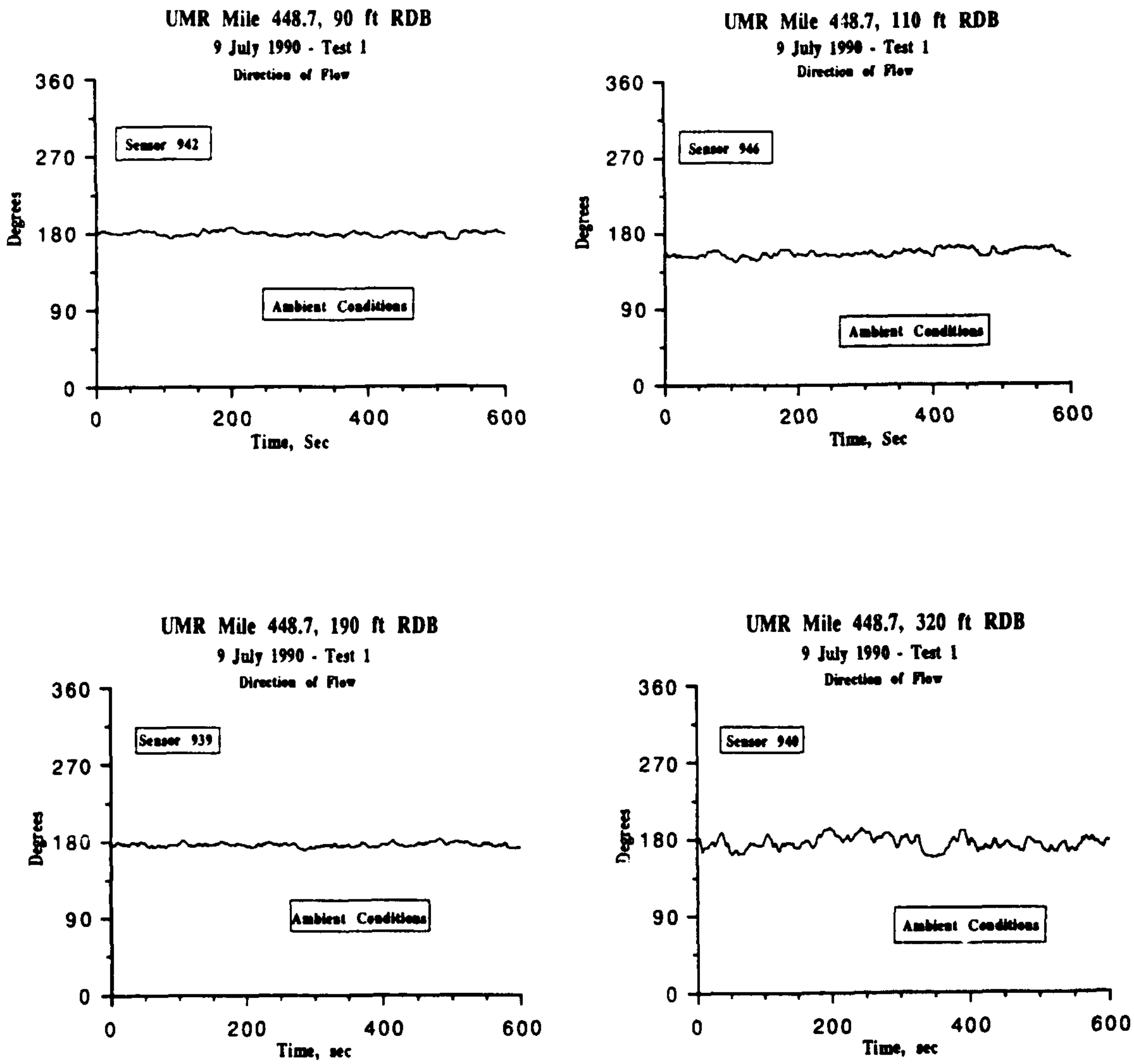

UMR Mile 448.7, 90 ft RDB
9 July 1990 - Test 1
Direction of Flow
Sensor 942
Ambient Conditions
Degrees
Time, Sec
0
90
180
270
360
200
400
600
UMR Mile 448.7, 110 ft RDB
9 July 1990 - Test 1
Direction of Flow
Sensor 946
Ambient Conditions
Degrees
Time, Sec
UMR Mile 448.7, 190 ft RDB
9 July 1990 - Test 1
Direction of Flow
Sensor 939
Ambient Conditions
Degrees
Time, sec
UMR Mile 448.7, 320 ft RDB
9 July 1990 - Test 1
Direction of Flow
Sensor 940
Ambient Conditions
Degrees
Time, sec

Figure E3

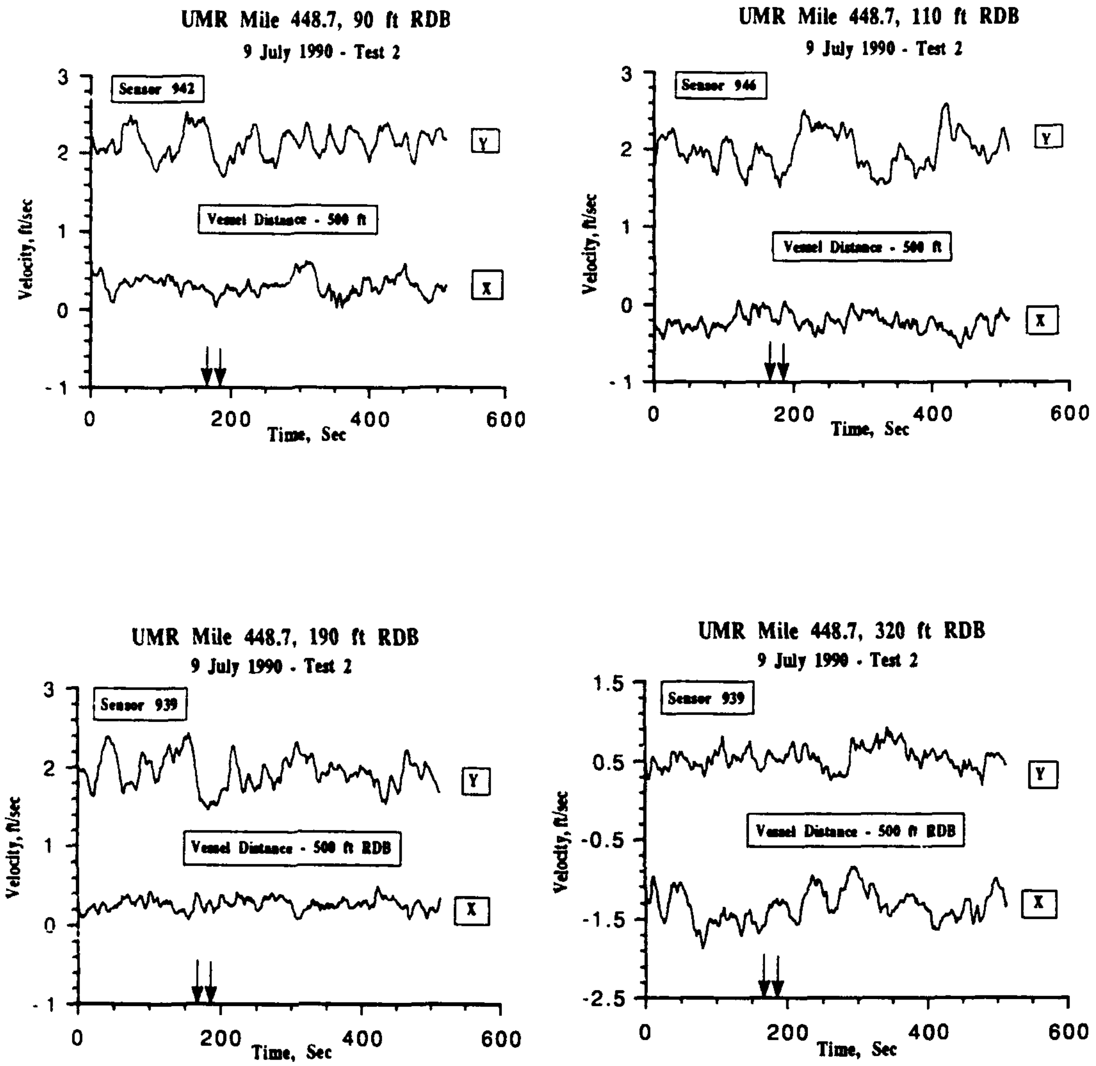
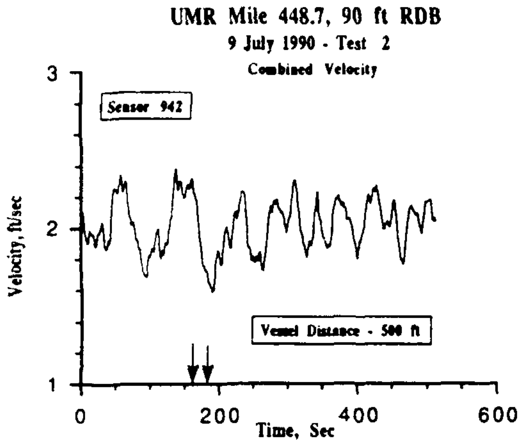
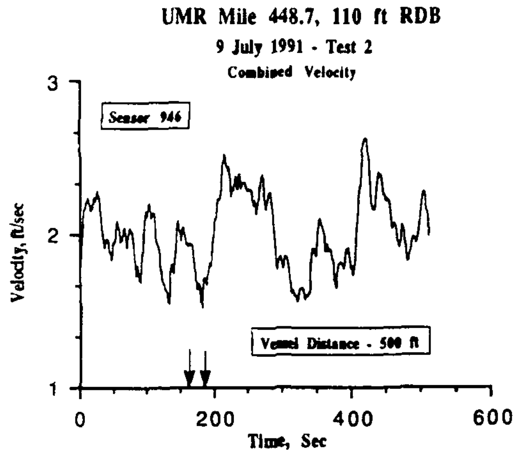
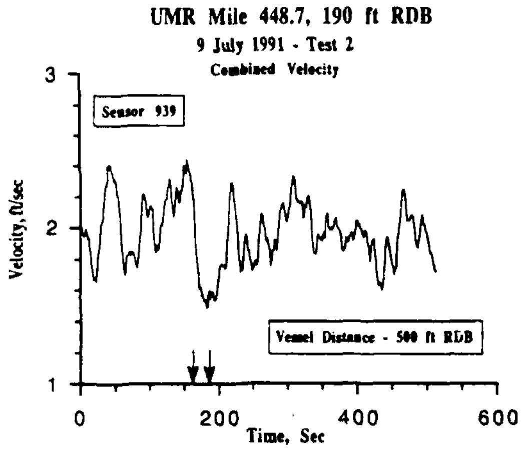

UMR Mile 448.7, 90 ft RDB
9 July 1990 - Test 2
Sensor 942
Vessel Distance - 500 ft
Y
X
Velocity, ft/sec
Time, Sec
UMR Mile 448.7, 110 ft RDB
9 July 1990 - Test 2
Sensor 946
Vessel Distance - 500 ft
Y
X
Velocity, ft/sec
Time, Sec
UMR Mile 448.7, 190 ft RDB
9 July 1990 - Test 2
Sensor 939
Vessel Distance - 500 ft RDB
Y
X
Velocity, ft/sec
Time, Sec
UMR Mile 448.7, 320 ft RDB
9 July 1990 - Test 2
Sensor 939
Vessel Distance - 500 ft RDB
Y
X
Velocity, ft/sec
Time, Sec

Figure E4


UMR Mile 448.7, 90 ft RDB
9 July 1990 - Test 2
Combined Velocity
Sensor 942
Vessel Distance - 500 ft
Velocity, ft/sec
Time, Sec
3
2
1
0
200
400
600


UMR Mile 448.7, 110 ft RDB
9 July 1991 - Test 2
Combined Velocity
Sensor 946
Vessel Distance - 500 ft
Velocity, ft/sec
Time, Sec
3
2
1
0
200
400
600


UMR Mile 448.7, 190 ft RDB
9 July 1991 - Test 2
Combined Velocity
Sensor 939
Vessel Distance - 500 ft RDB
Velocity, ft/sec
Time, Sec
3
2
1
0
200
400
600

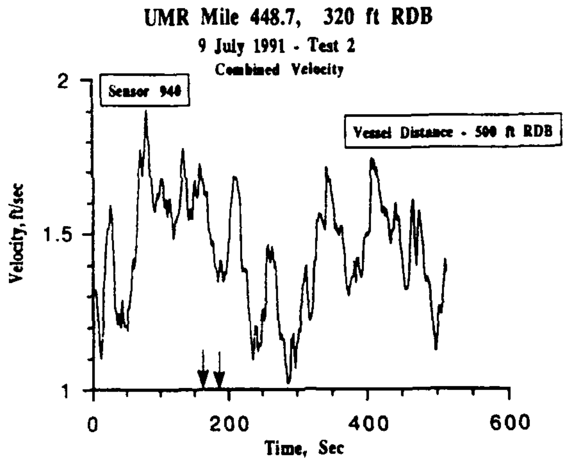

UMR Mile 448.7, 320 ft RDB
9 July 1991 - Test 2
Combined Velocity
Sensor 940
Vessel Distance - 500 ft RDB
Velocity, ft/sec
Time, Sec
2
1.5
1
0
200
400
600

Figure E5

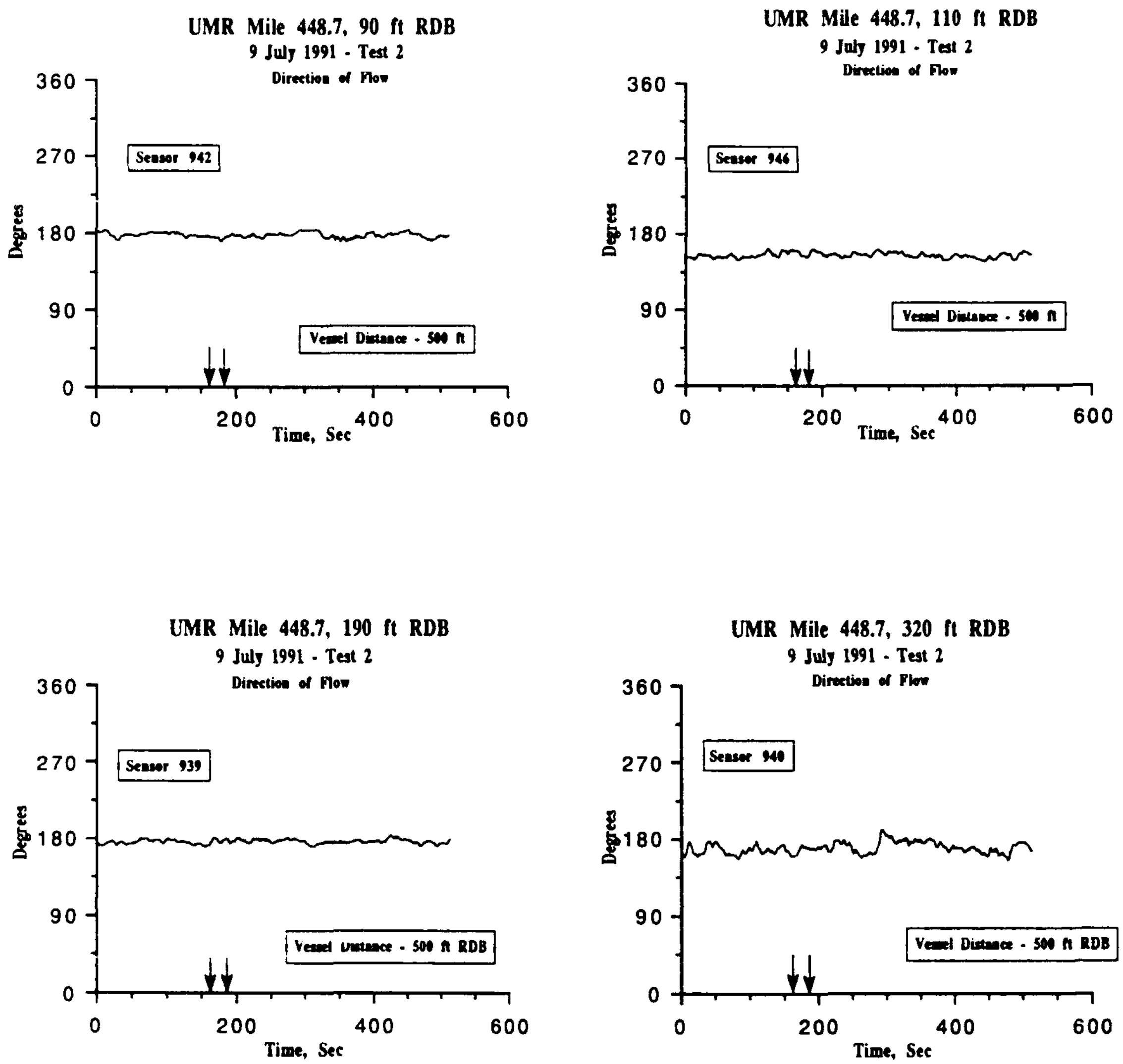

UMR Mile 448.7, 90 ft RDB
9 July 1991 - Test 2
Direction of Flow
Sensor 942
Vessel Distance - 500 ft
Degrees
Time, Sec
UMR Mile 448.7, 110 ft RDB
9 July 1991 - Test 2
Direction of Flow
Sensor 946
Vessel Distance - 500 ft
Degrees
Time, Sec
UMR Mile 448.7, 190 ft RDB
9 July 1991 - Test 2
Direction of Flow
Sensor 939
Vessel Distance - 500 ft RDB
Degrees
Time, Sec
UMR Mile 448.7, 320 ft RDB
9 July 1991 - Test 2
Direction of Flow
Sensor 940
Vessel Distance - 500 ft RDB
Degrees
Time, Sec

Figure E6

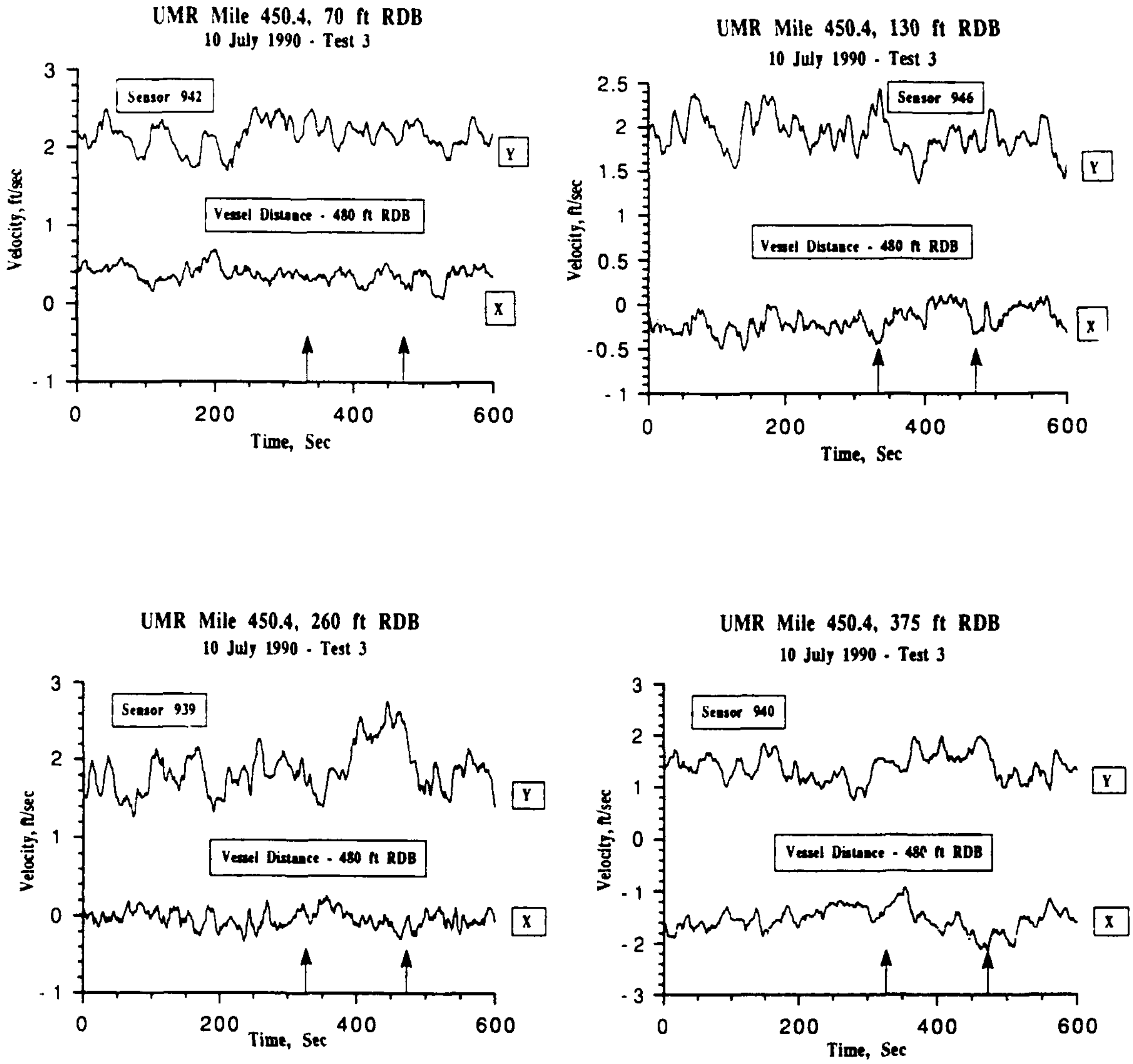

UMR Mile 450.4, 70 ft RDB
10 July 1990 - Test 3
Sensor 942
Vessel Distance - 480 ft RDB
Y
X
Velocity, ft/sec
Time, Sec
UMR Mile 450.4, 130 ft RDB
10 July 1990 - Test 3
Sensor 946
Vessel Distance - 480 ft RDB
Y
X
Velocity, ft/sec
Time, Sec
UMR Mile 450.4, 260 ft RDB
10 July 1990 - Test 3
Sensor 939
Vessel Distance - 480 ft RDB
Y
X
Velocity, ft/sec
Time, Sec
UMR Mile 450.4, 375 ft RDB
10 July 1990 - Test 3
Sensor 940
Vessel Distance - 480 ft RDB
Y
X
Velocity, ft/sec
Time, Sec

Figure E7

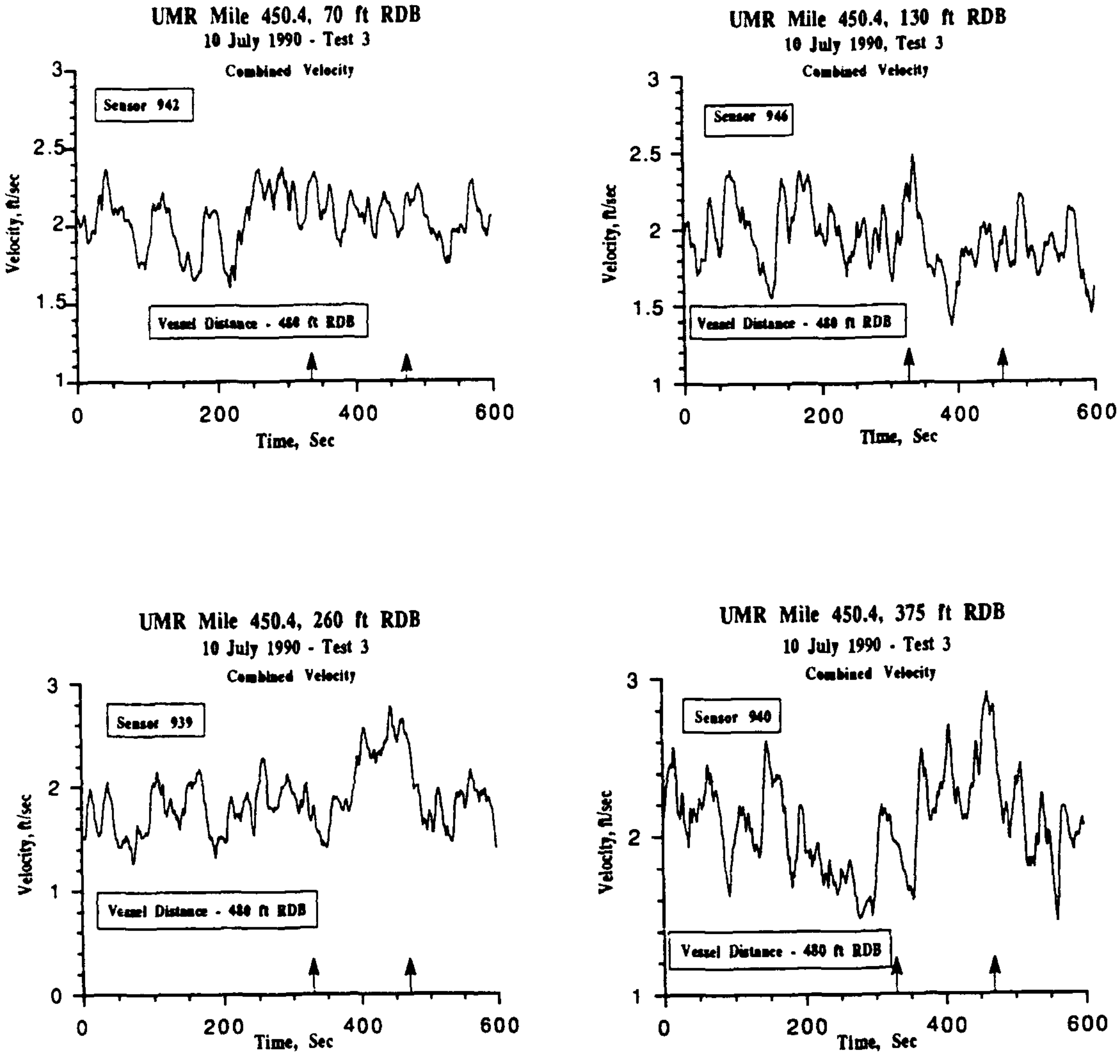

UMR Mile 450.4, 70 ft RDB
10 July 1990 - Test 3
Combined Velocity
Sensor 942
Vessel Distance - 480 ft RDB
Velocity, ft/sec
Time, Sec
UMR Mile 450.4, 130 ft RDB
10 July 1990, Test 3
Combined Velocity
Sensor 946
Vessel Distance - 480 ft RDB
Velocity, ft/sec
Time, Sec
UMR Mile 450.4, 260 ft RDB
10 July 1990 - Test 3
Combined Velocity
Sensor 939
Vessel Distance - 480 ft RDB
Velocity, ft/sec
Time, Sec
UMR Mile 450.4, 375 ft RDB
10 July 1990 - Test 3
Combined Velocity
Sensor 940
Vessel Distance - 480 ft RDB
Velocity, ft/sec
Time, Sec

Figure E8

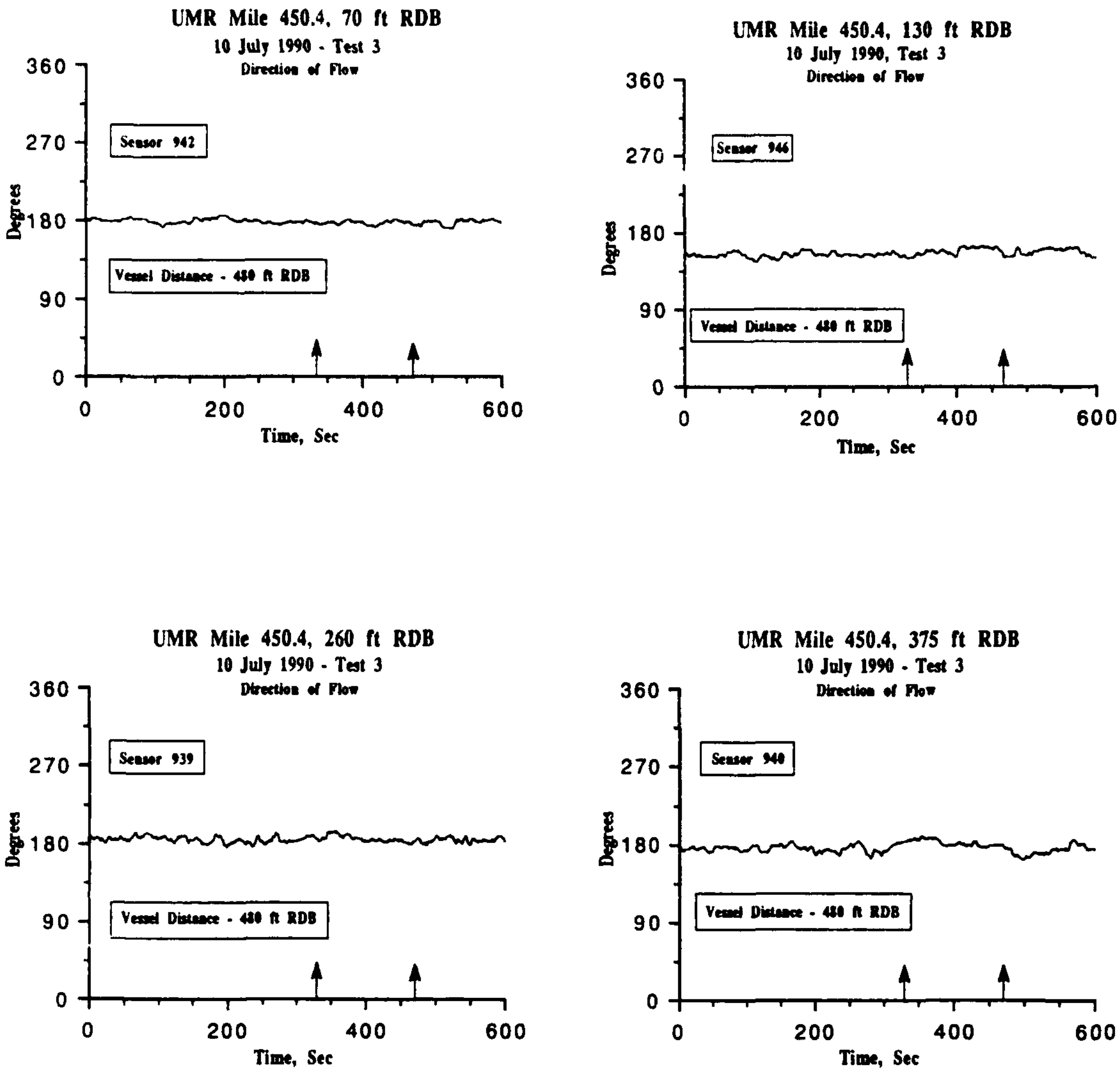

UMR Mile 450.4, 70 ft RDB
10 July 1990 - Test 3
Direction of Flow
Sensor 942
Vessel Distance - 480 ft RDB
Degrees
Time, Sec
UMR Mile 450.4, 130 ft RDB
10 July 1990, Test 3
Direction of Flow
Sensor 946
Vessel Distance - 480 ft RDB
Degrees
Time, Sec
UMR Mile 450.4, 260 ft RDB
10 July 1990 - Test 3
Direction of Flow
Sensor 939
Vessel Distance - 480 ft RDB
Degrees
Time, Sec
UMR Mile 450.4, 375 ft RDB
10 July 1990 - Test 3
Direction of Flow
Sensor 940
Vessel Distance - 480 ft RDB
Degrees
Time, Sec

Figure E9

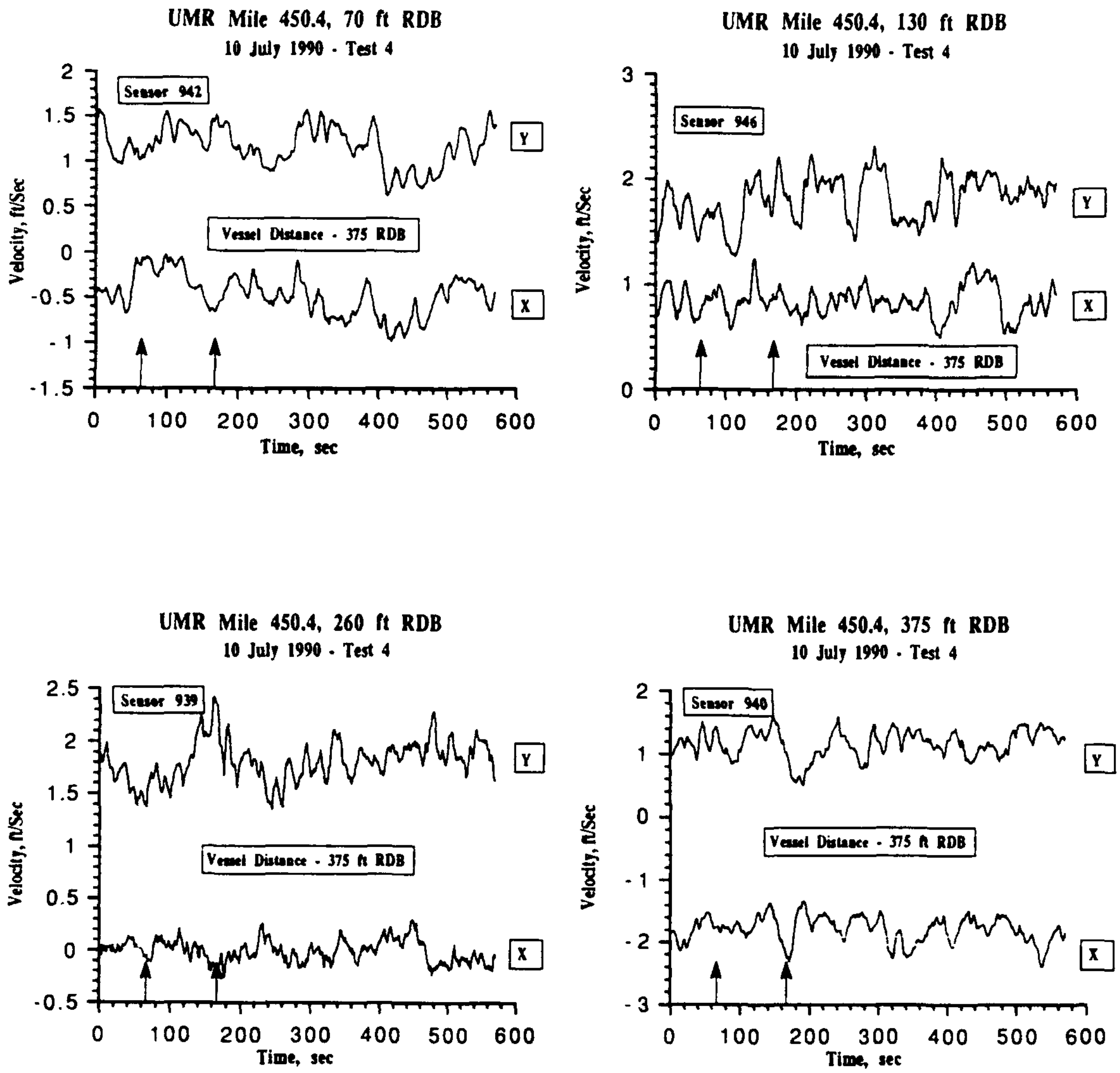
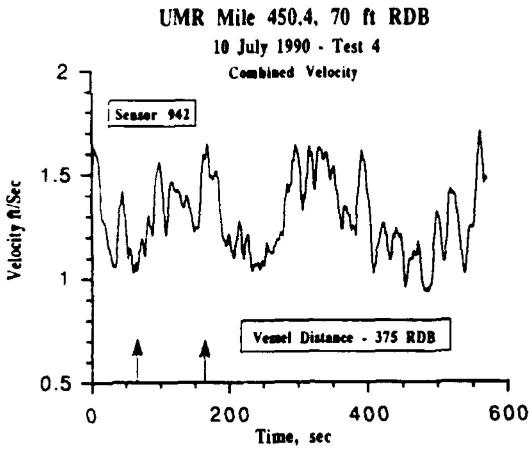
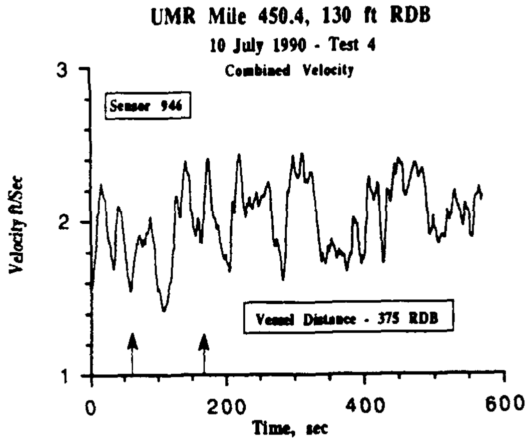
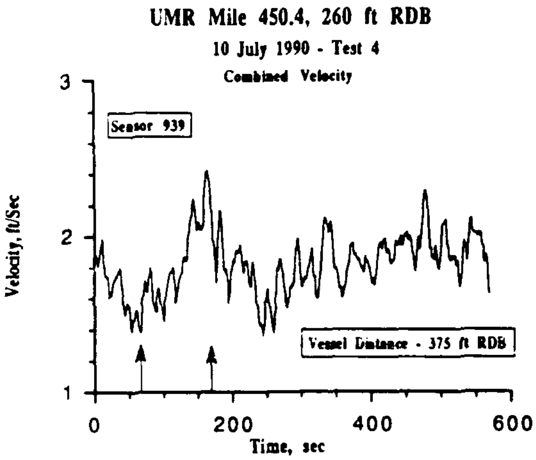

UMR Mile 450.4, 70 ft RDB
10 July 1990 - Test 4
Sensor 942
Vessel Distance - 375 RDB
Y
X
Velocity, ft/Sec
Time, sec
UMR Mile 450.4, 130 ft RDB
10 July 1990 - Test 4
Sensor 946
Vessel Distance - 375 RDB
UMR Mile 450.4, 260 ft RDB
10 July 1990 - Test 4
Sensor 939
Vessel Distance - 375 ft RDB
UMR Mile 450.4, 375 ft RDB
10 July 1990 - Test 4
Sensor 940
Vessel Distance - 375 ft RDB

Figure E10


UMR Mile 450.4, 70 ft RDB
10 July 1990 - Test 4
Combined Velocity
Sensor 942
Vessel Distance - 375 RDB
Velocity ft/Sec
Time, sec
0.5
1
1.5
2
0
200
400
600


UMR Mile 450.4, 130 ft RDB
10 July 1990 - Test 4
Combined Velocity
Sensor 946
Vessel Distance - 375 RDB
Velocity ft/Sec
Time, sec
1
2
3
0
200
400
600


UMR Mile 450.4, 260 ft RDB
10 July 1990 - Test 4
Combined Velocity
Sensor 939
Vessel Distance - 375 ft RDB
Velocity, ft/Sec
Time, sec
1
2
3
0
200
400
600

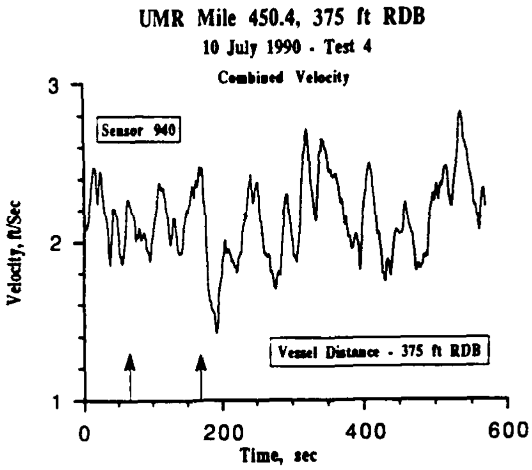

UMR Mile 450.4, 375 ft RDB
10 July 1990 - Test 4
Combined Velocity
Sensor 940
Vessel Distance - 375 ft RDB
Velocity, ft/Sec
Time, sec
1
2
3
0
200
400
600

Figure E11

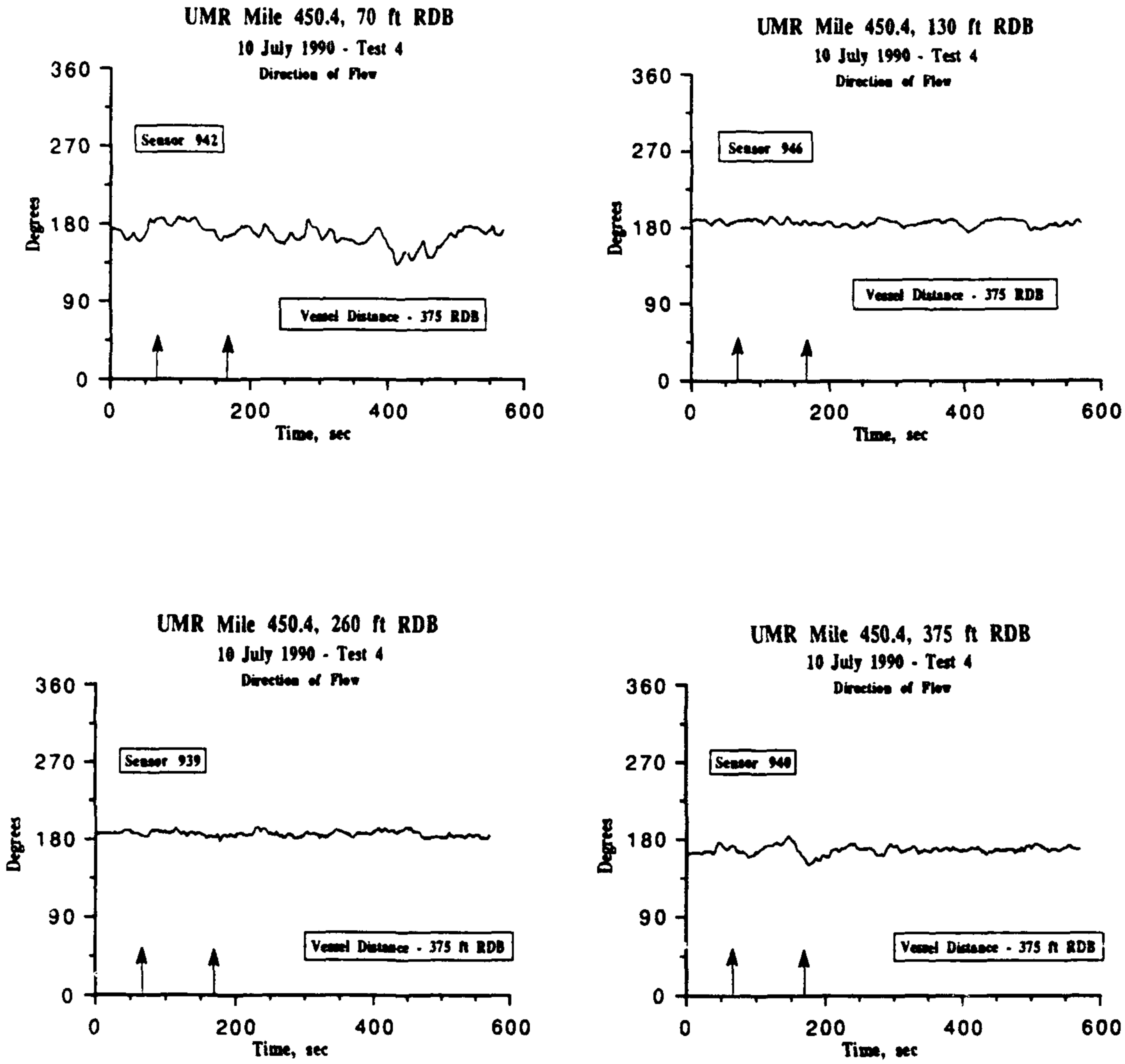

UMR Mile 450.4, 70 ft RDB
10 July 1990 - Test 4
Direction of Flow
Sensor 942
Vessel Distance - 375 RDB
Degrees
Time, sec
0
90
180
270
360
0
200
400
600
UMR Mile 450.4, 130 ft RDB
10 July 1990 - Test 4
Direction of Flow
Sensor 946
Vessel Distance - 375 RDB
Degrees
Time, sec
0
90
180
270
360
0
200
400
600
UMR Mile 450.4, 260 ft RDB
10 July 1990 - Test 4
Direction of Flow
Sensor 939
Vessel Distance - 375 ft RDB
Degrees
Time, sec
0
90
180
270
360
0
200
400
600
UMR Mile 450.4, 375 ft RDB
10 July 1990 - Test 4
Direction of Flow
Sensor 940
Vessel Distance - 375 ft RDB
Degrees
Time, sec
0
90
180
270
360
0
200
400
600

Figure E12

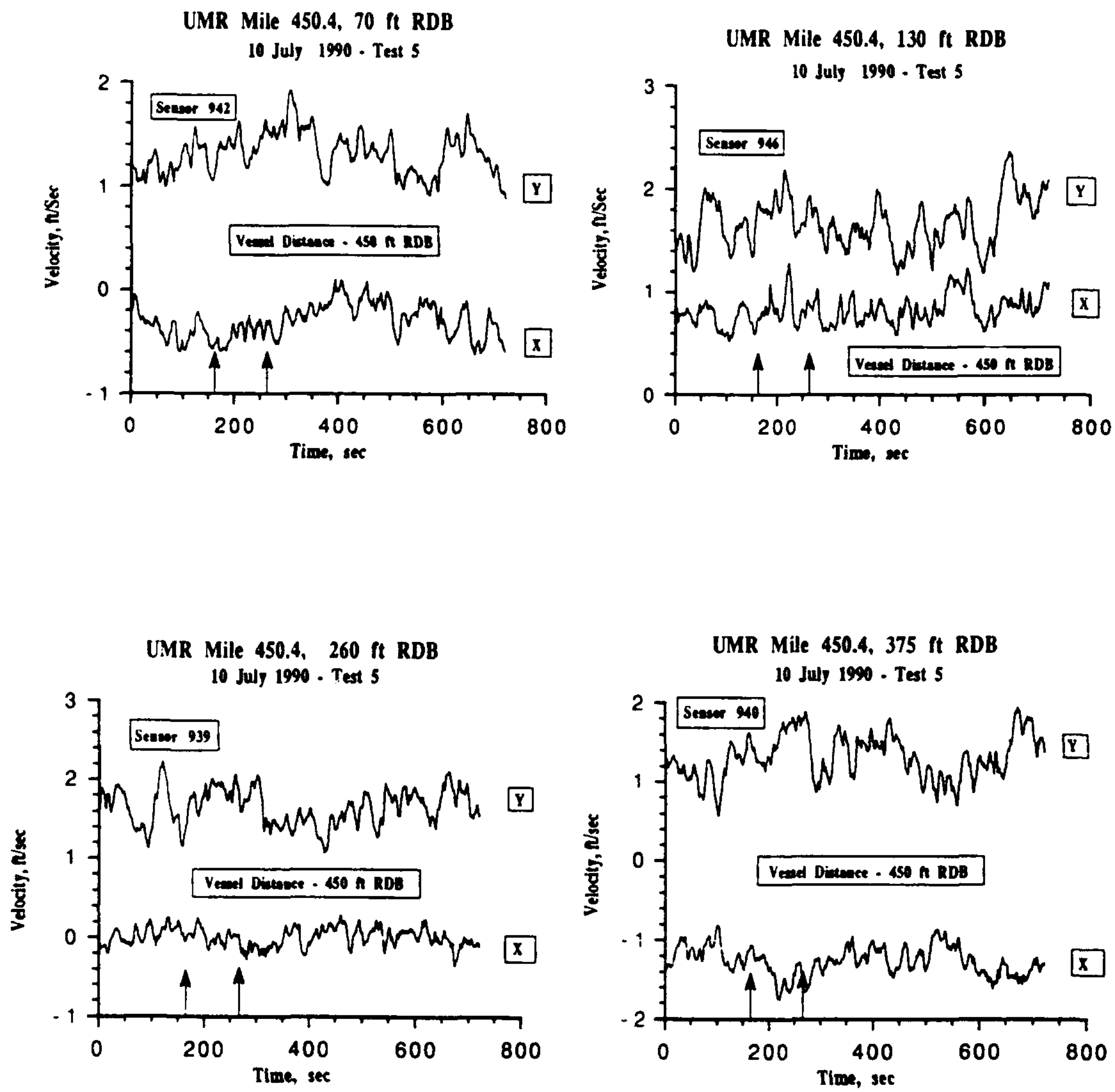

UMR Mile 450.4, 70 ft RDB
10 July 1990 - Test 5
Sensor 942
Vessel Distance - 450 ft RDB
Y
X
Velocity, ft/Sec
Time, sec
UMR Mile 450.4, 130 ft RDB
10 July 1990 - Test 5
Sensor 946
Vessel Distance - 450 ft RDB
Y
X
Velocity, ft/Sec
Time, sec
UMR Mile 450.4, 260 ft RDB
10 July 1990 - Test 5
Sensor 939
Vessel Distance - 450 ft RDB
Y
X
Velocity, ft/sec
Time, sec
UMR Mile 450.4, 375 ft RDB
10 July 1990 - Test 5
Sensor 940
Vessel Distance - 450 ft RDB
Y
X
Velocity, ft/sec
Time, sec

Figure E13

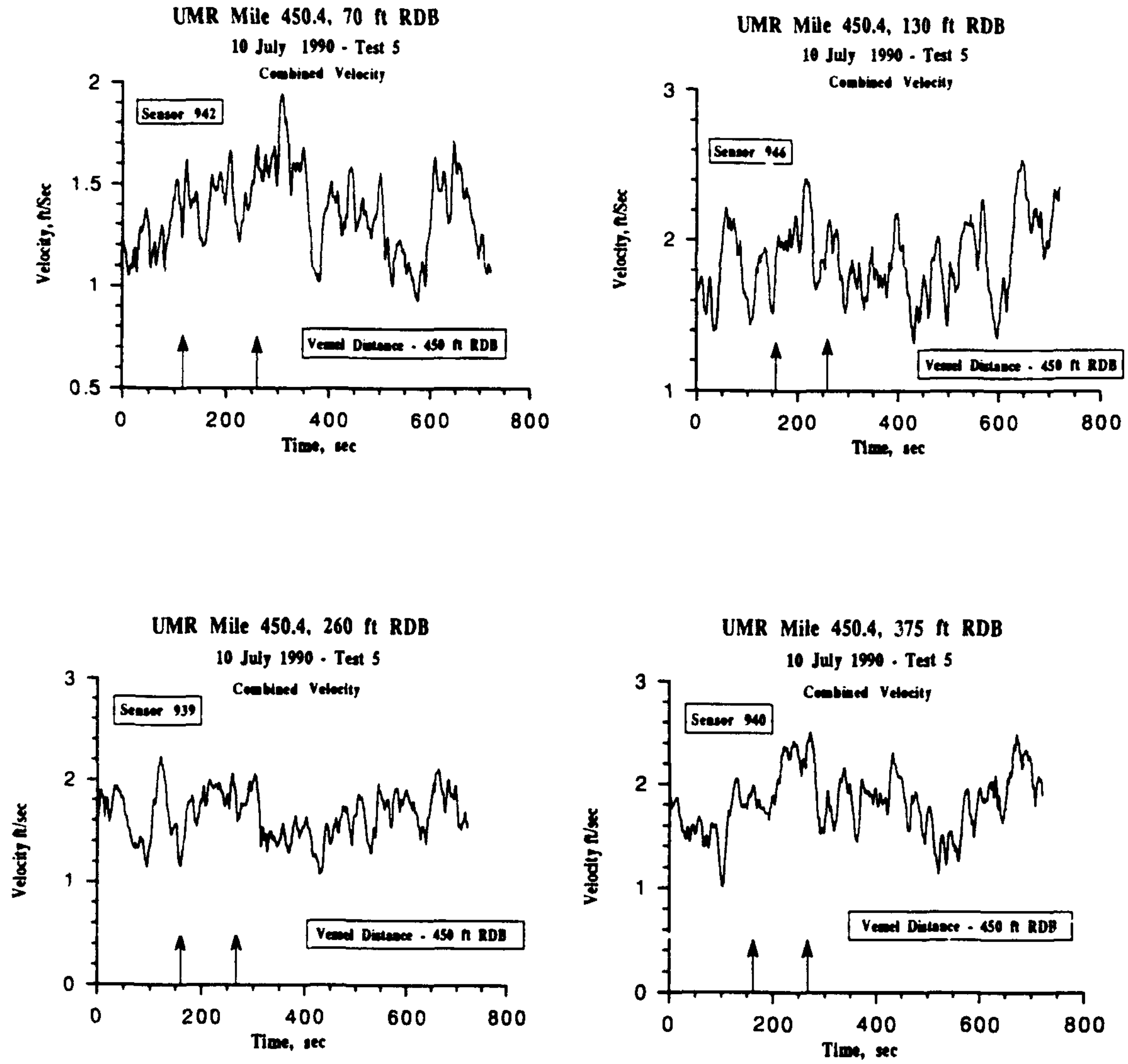
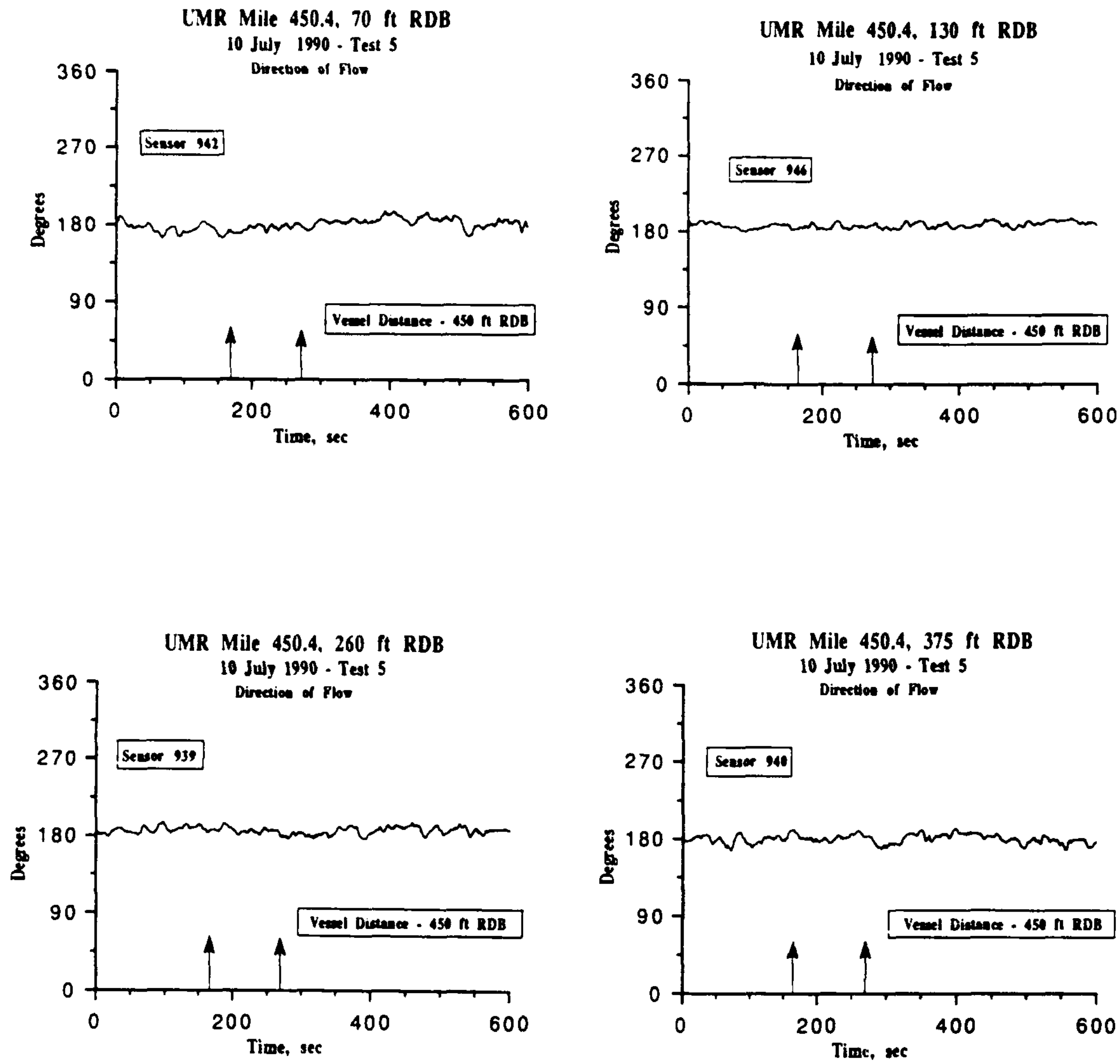

UMR Mile 450.4, 70 ft RDB
10 July 1990 - Test 5
Combined Velocity
Sensor 942
Vessel Distance - 450 ft RDB
Velocity, ft/Sec
Time, sec
UMR Mile 450.4, 130 ft RDB
10 July 1990 - Test 5
Combined Velocity
Sensor 946
Vessel Distance - 450 ft RDB
Velocity, ft/Sec
Time, sec
UMR Mile 450.4, 260 ft RDB
10 July 1990 - Test 5
Combined Velocity
Sensor 939
Vessel Distance - 450 ft RDB
Velocity ft/sec
Time, sec
UMR Mile 450.4, 375 ft RDB
10 July 1990 - Test 5
Combined Velocity
Sensor 940
Vessel Distance - 450 ft RDB
Velocity ft/sec
Time, sec

Figure E14



UMR Mile 450.4, 70 ft RDB
10 July 1990 - Test 5
Direction of Flow
Sensor 942
Vessel Distance - 450 ft RDB
Degrees
Time, sec
UMR Mile 450.4, 130 ft RDB
10 July 1990 - Test 5
Direction of Flow
Sensor 946
Vessel Distance - 450 ft RDB
Degrees
Time, sec
UMR Mile 450.4, 260 ft RDB
10 July 1990 - Test 5
Direction of Flow
Sensor 939
Vessel Distance - 450 ft RDB
Degrees
Time, sec
UMR Mile 450.4, 375 ft RDB
10 July 1990 - Test 5
Direction of Flow
Sensor 940
Vessel Distance - 450 ft RDB
Degrees
Time, sec

Figure E15

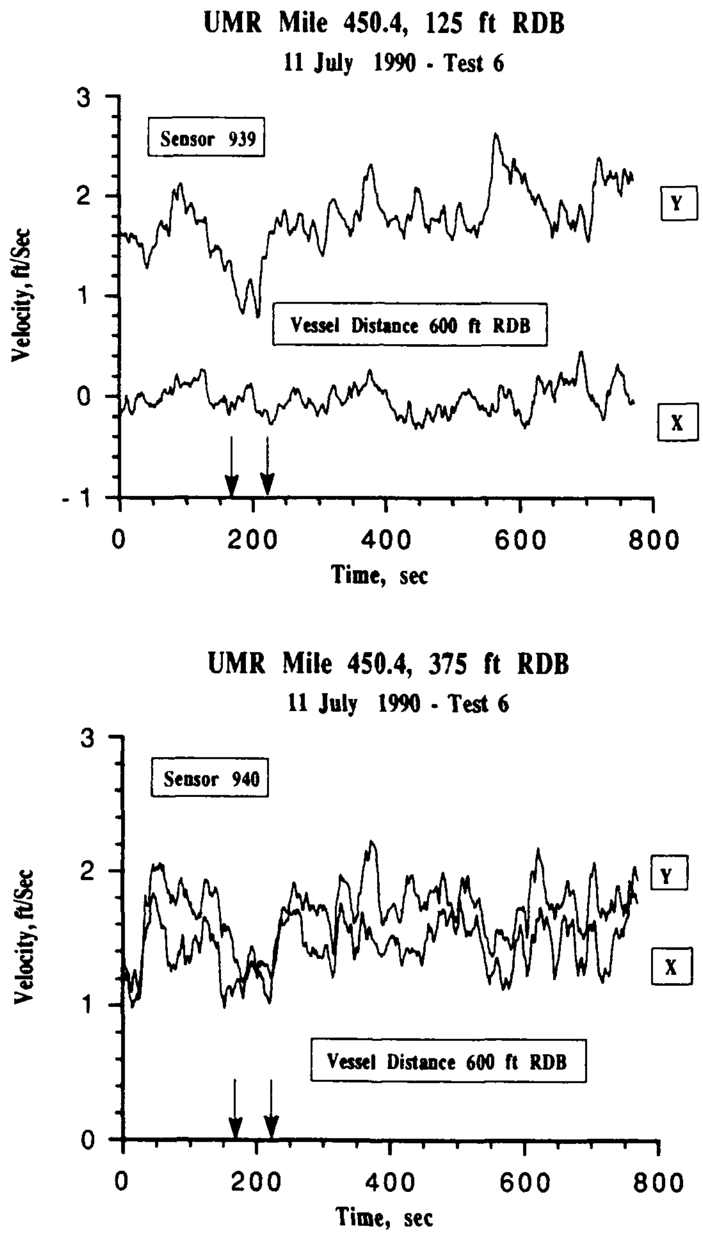
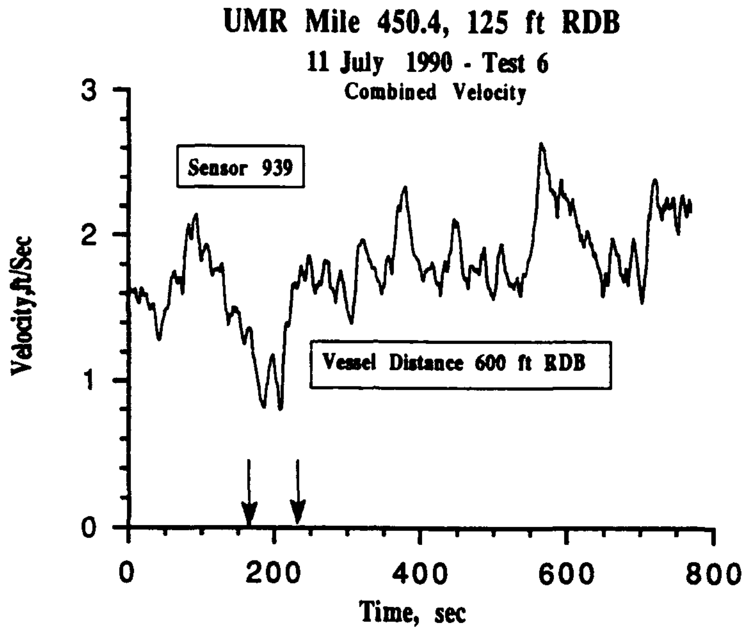
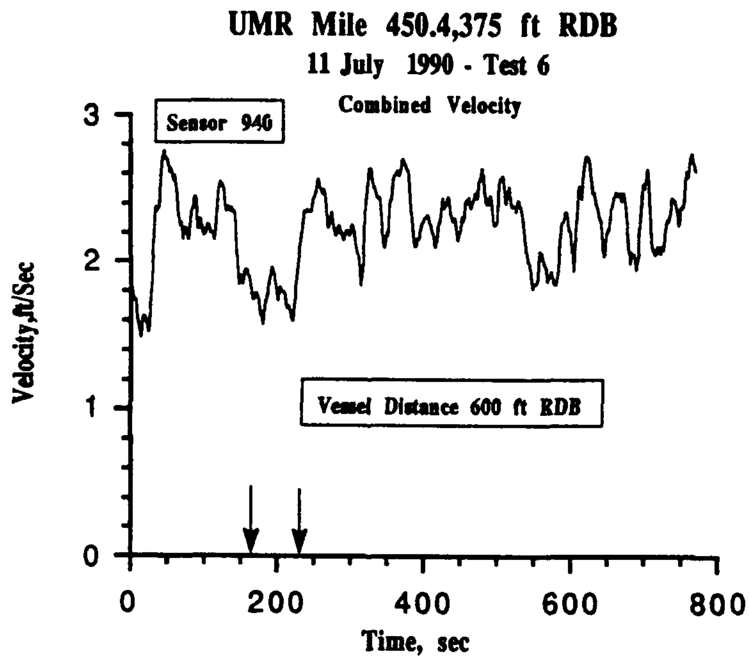

UMR Mile 450.4, 125 ft RDB
11 July 1990 - Test 6
Sensor 939
Velocity, ft/Sec
Vessel Distance 600 ft RDB
Y
X
3
2
1
0
- 1
0
200
400
600
800
Time, sec
UMR Mile 450.4, 375 ft RDB
11 July 1990 - Test 6
Sensor 940
Velocity, ft/Sec
Vessel Distance 600 ft RDB
Y
X
3
2
1
0
0
200
400
600
800
Time, sec

Figure E16

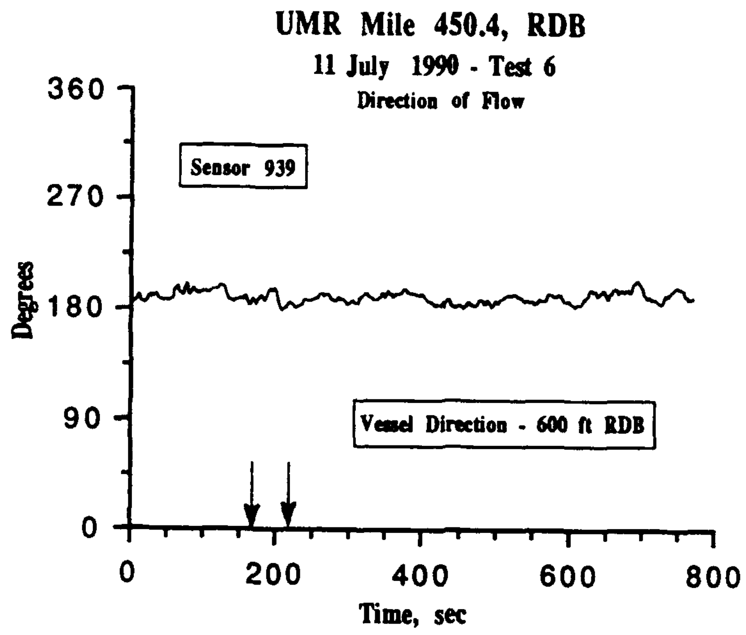


UMR Mile 450.4, 125 ft RDB
11 July 1990 - Test 6
Combined Velocity
Sensor 939
Vessel Distance 600 ft RDB
Velocity,ft/Sec
Time, sec
0
1
2
3
0
200
400
600
800



UMR Mile 450.4,375 ft RDB
11 July 1990 - Test 6
Combined Velocity
Sensor 940
Vessel Distance 600 ft RDB
Velocity,ft/Sec
Time, sec
0
1
2
3
0
200
400
600
800

Figure E17


UMR Mile 450.4, RDB
11 July 1990 - Test 6
Direction of Flow
Sensor 939
Vessel Direction - 600 ft RDB
Degrees
360
270
180
90
0
0
200
400
600
800
Time, sec

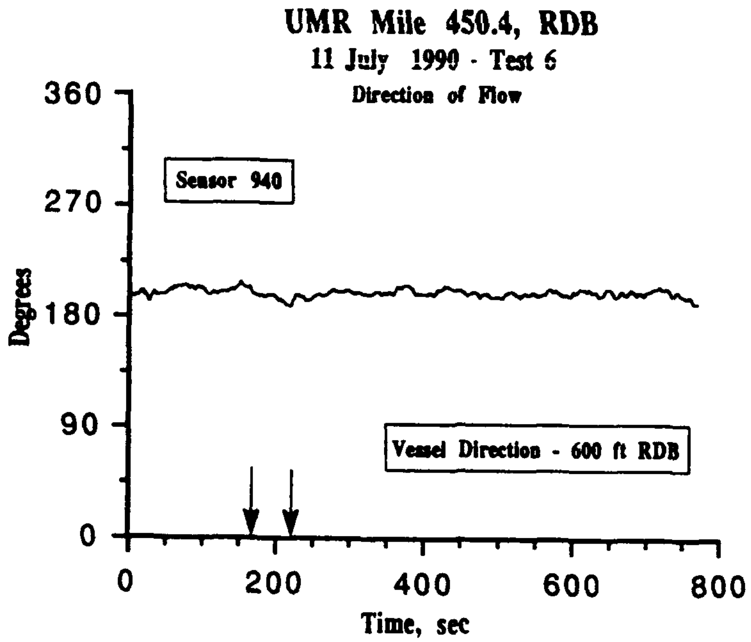
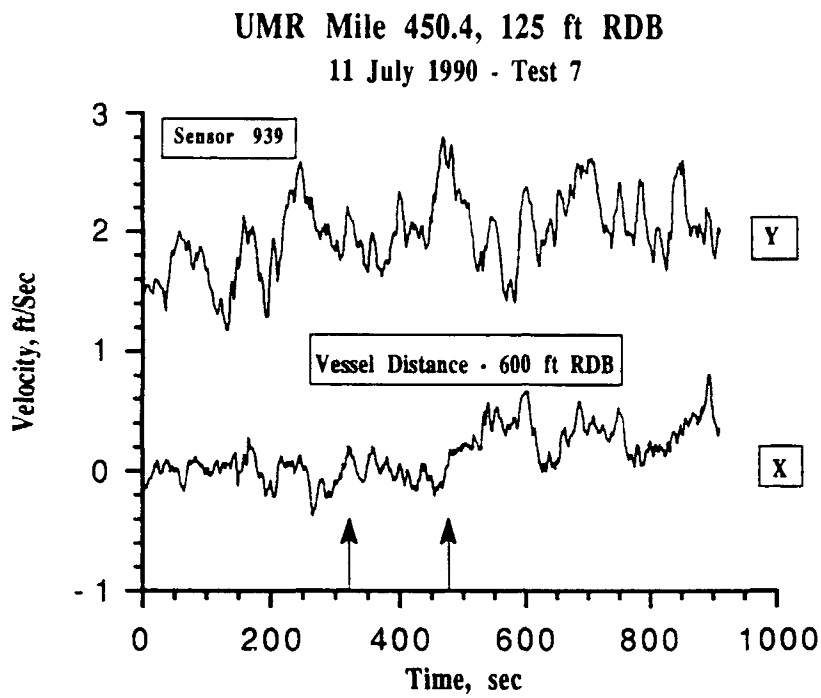

UMR Mile 450.4, RDB
11 July 1990 - Test 6
Direction of Flow
Sensor 940
Vessel Direction - 600 ft RDB
Degrees
360
270
180
90
0
0
200
400
600
800
Time, sec

Figure E18


UMR Mile 450.4, 125 ft RDB
11 July 1990 - Test 7
Sensor 939
Vessel Distance - 600 ft RDB
Y
X
Velocity, ft/Sec
Time, sec
3
2
1
0
- 1
0
200
400
600
800
1000

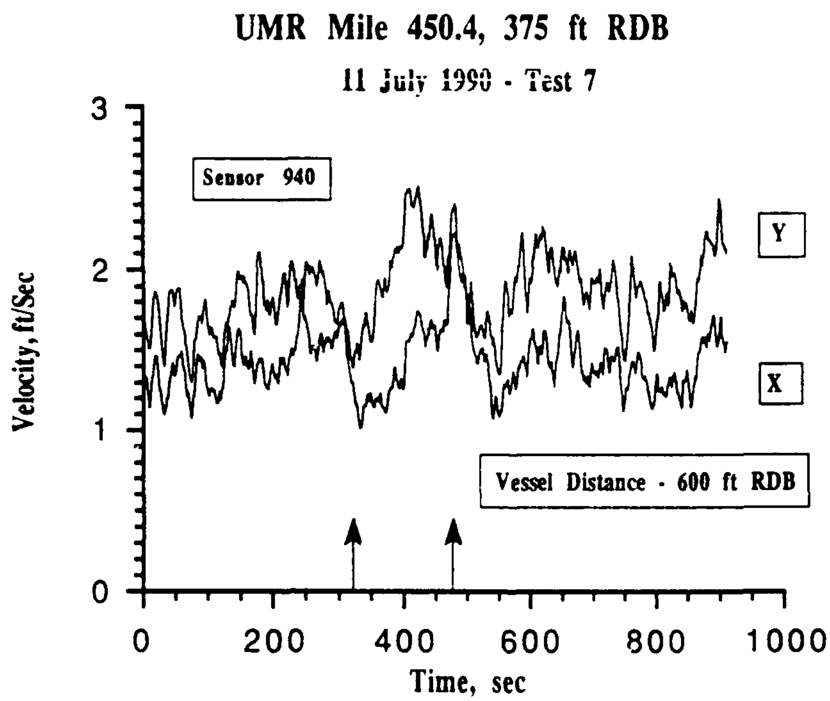
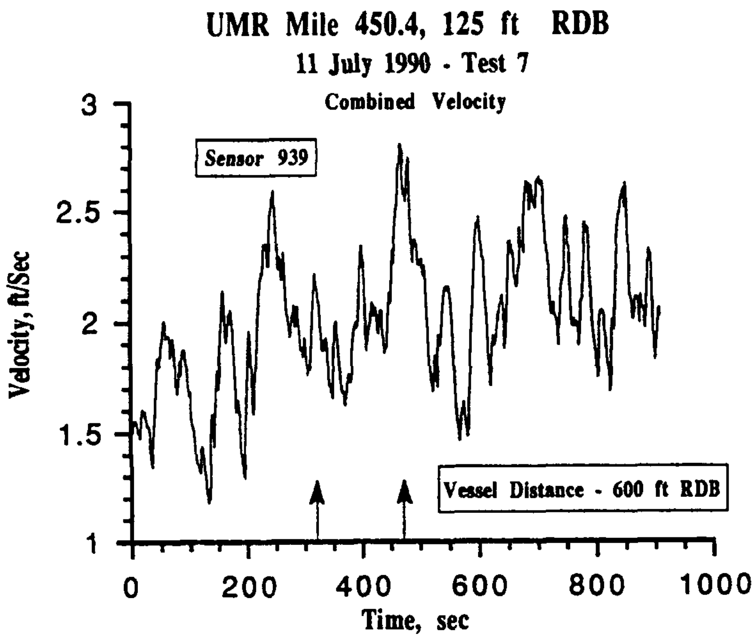

UMR Mile 450.4, 375 ft RDB
11 July 1990 - Test 7
Sensor 940
Vessel Distance - 600 ft RDB
Y
X
Velocity, ft/Sec
Time, sec
3
2
1
0
0
200
400
600
800
1000

Figure E19


UMR Mile 450.4, 125 ft RDB
11 July 1990 - Test 7
Combined Velocity
Sensor 939
Vessel Distance - 600 ft RDB
Velocity, ft/Sec
Time, sec
3
2.5
2
1.5
1
0
200
400
600
800
1000

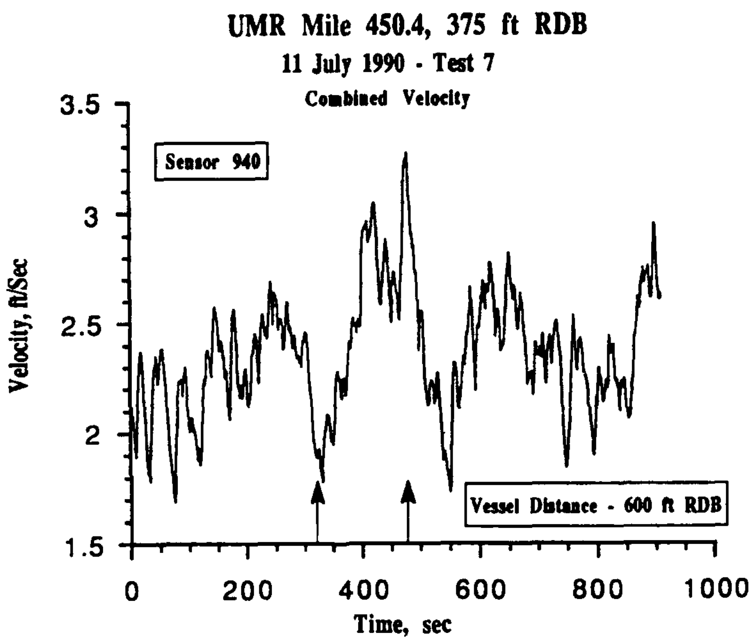
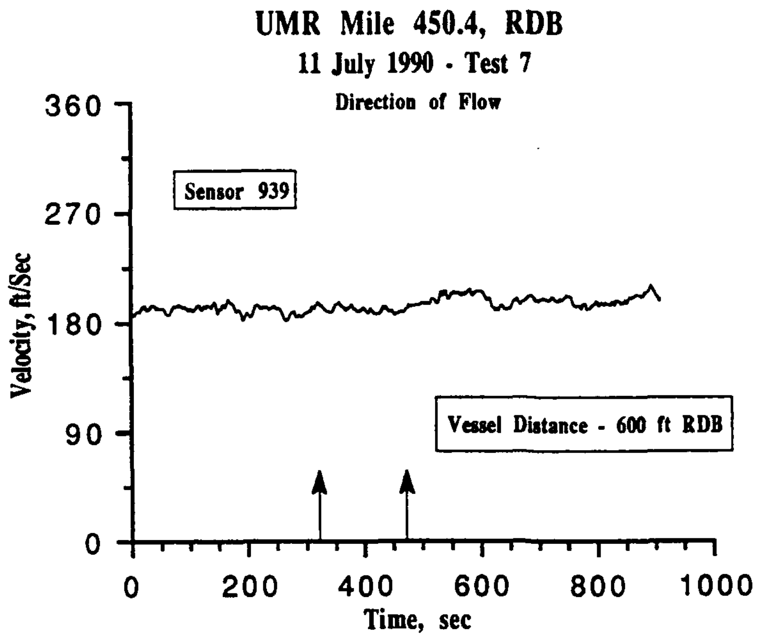

UMR Mile 450.4, 375 ft RDB
11 July 1990 - Test 7
Combined Velocity
Sensor 940
Vessel Distance - 600 ft RDB
Velocity, ft/Sec
Time, sec
3.5
3
2.5
2
1.5
0
200
400
600
800
1000

Figure E20


UMR Mile 450.4, RDB
11 July 1990 - Test 7
Direction of Flow
Sensor 939
Vessel Distance - 600 ft RDB
Velocity, ft/Sec
Time, sec
360
270
180
90
0
0
200
400
600
800
1000

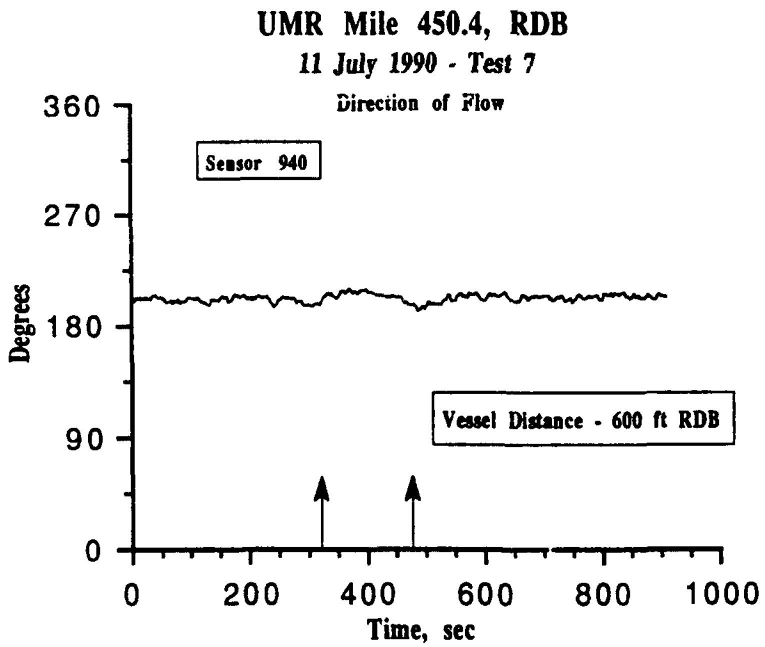
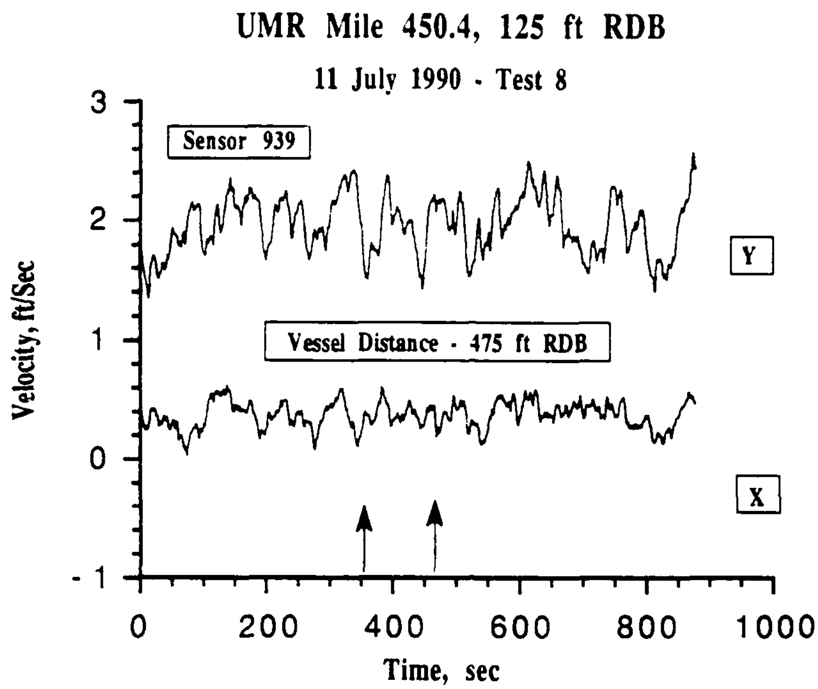
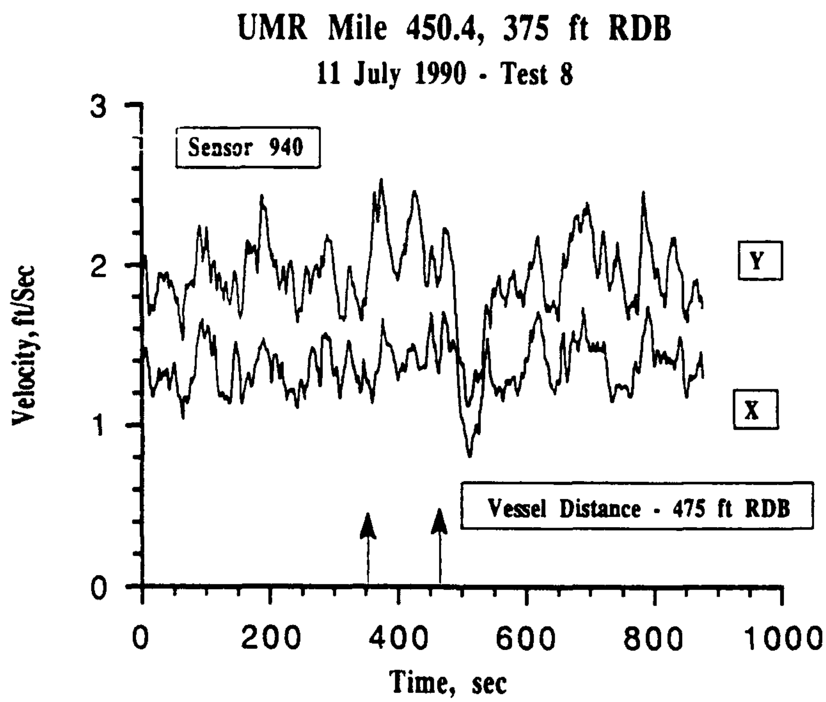

UMR Mile 450.4, RDB
11 July 1990 - Test 7
Direction of Flow
Sensor 940
Vessel Distance - 600 ft RDB
Degrees
Time, sec
360
270
180
90
0
0
200
400
600
800
1000

Figure E21

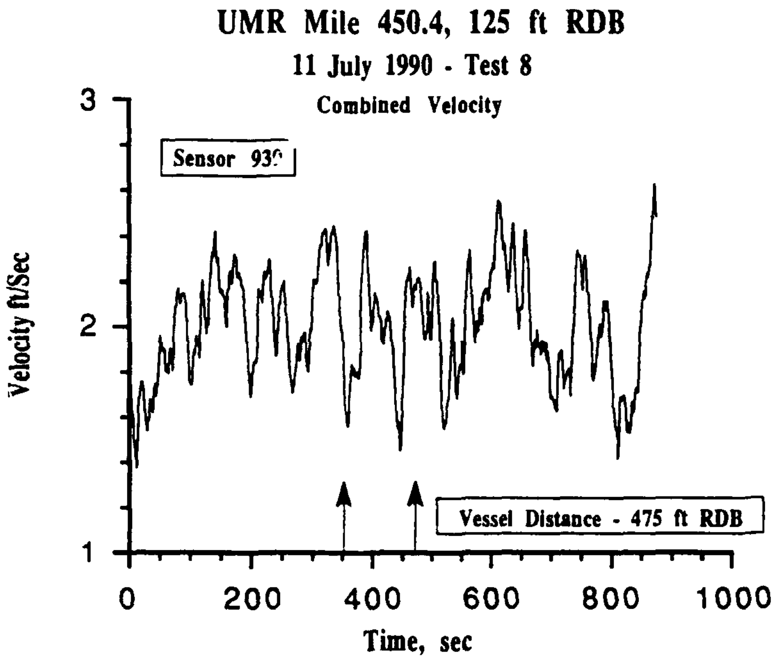


UMR Mile 450.4, 125 ft RDB
11 July 1990 - Test 8
Sensor 939
Vessel Distance - 475 ft RDB
Y
X
Velocity, ft/Sec
Time, sec
3
2
1
0
- 1
0
200
400
600
800
1000



UMR Mile 450.4, 375 ft RDB
11 July 1990 - Test 8
Sensor 940
Y
X
Vessel Distance - 475 ft RDB
Velocity, ft/Sec
Time, sec
3
2
1
0
0
200
400
600
800
1000

Figure E22


UMR Mile 450.4, 125 ft RDB
11 July 1990 - Test 8
Combined Velocity
Sensor 939
Velocity ft/Sec
Vessel Distance - 475 ft RDB
Time, sec
3
2
1
0
200
400
600
800
1000

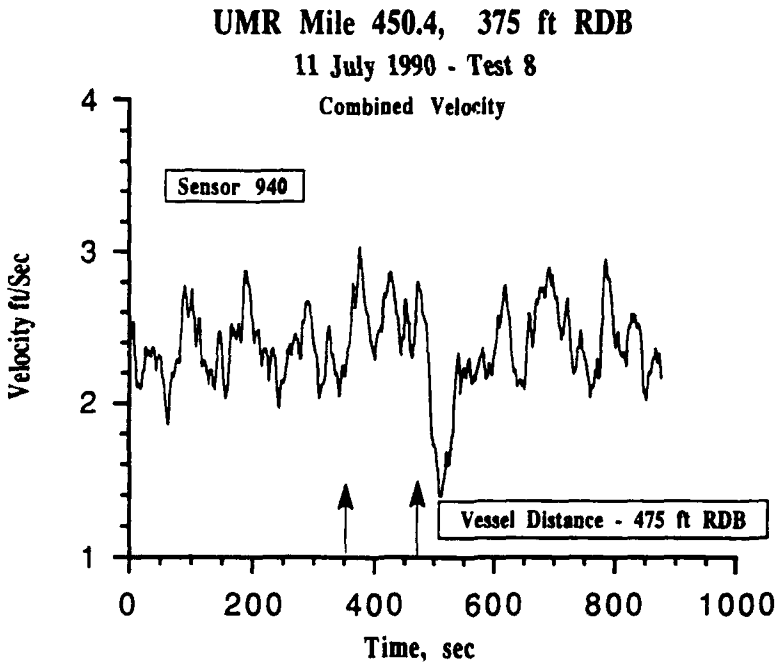
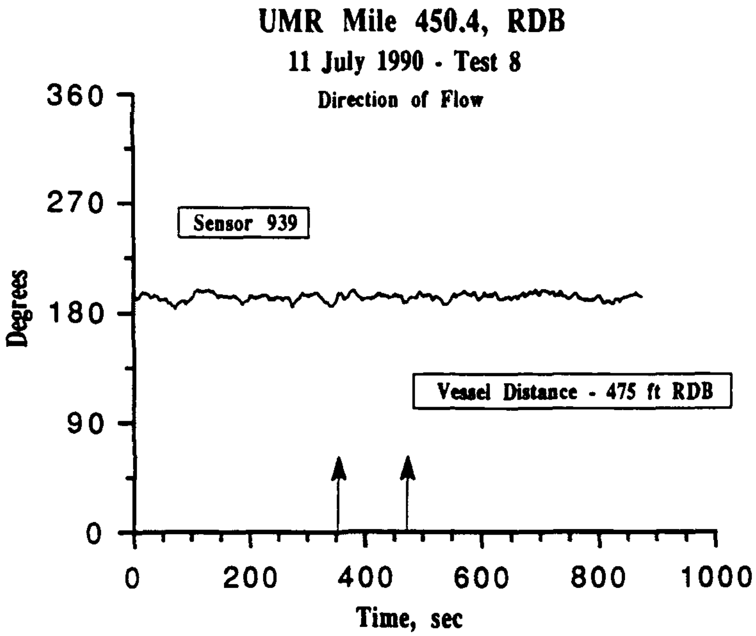

UMR Mile 450.4, 375 ft RDB
11 July 1990 - Test 8
Combined Velocity
Sensor 940
Velocity ft/Sec
Vessel Distance - 475 ft RDB
Time, sec
4
3
2
1
0
200
400
600
800
1000

Figure E23


UMR Mile 450.4, RDB
11 July 1990 - Test 8
Direction of Flow
360
270
180
90
0
Degrees
Sensor 939
Vessel Distance - 475 ft RDB
0
200
400
600
800
1000
Time, sec

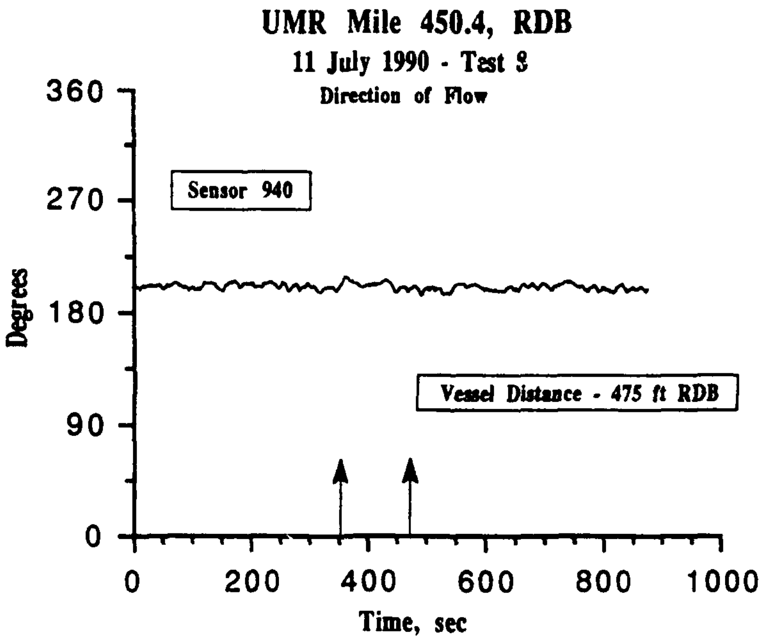
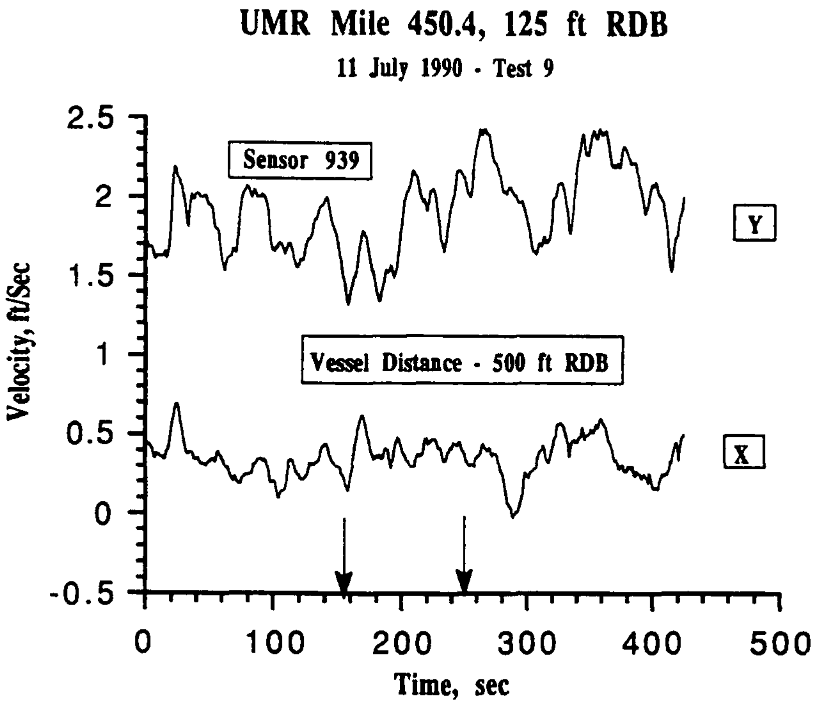

UMR Mile 450.4, RDB
11 July 1990 - Test 8
Direction of Flow
360
270
180
90
0
Degrees
Sensor 940
Vessel Distance - 475 ft RDB
0
200
400
600
800
1000
Time, sec

Figure E24


UMR Mile 450.4, 125 ft RDB
11 July 1990 - Test 9
Sensor 939
Vessel Distance - 500 ft RDB
Y
X
Velocity, ft/Sec
Time, sec
2.5
2
1.5
1
0.5
0
-0.5
0
100
200
300
400
500

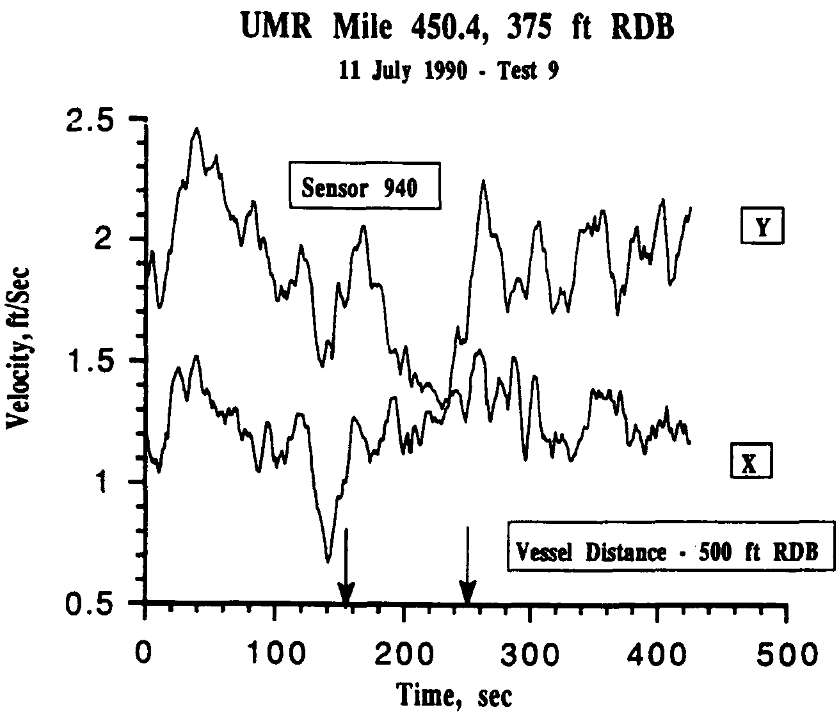
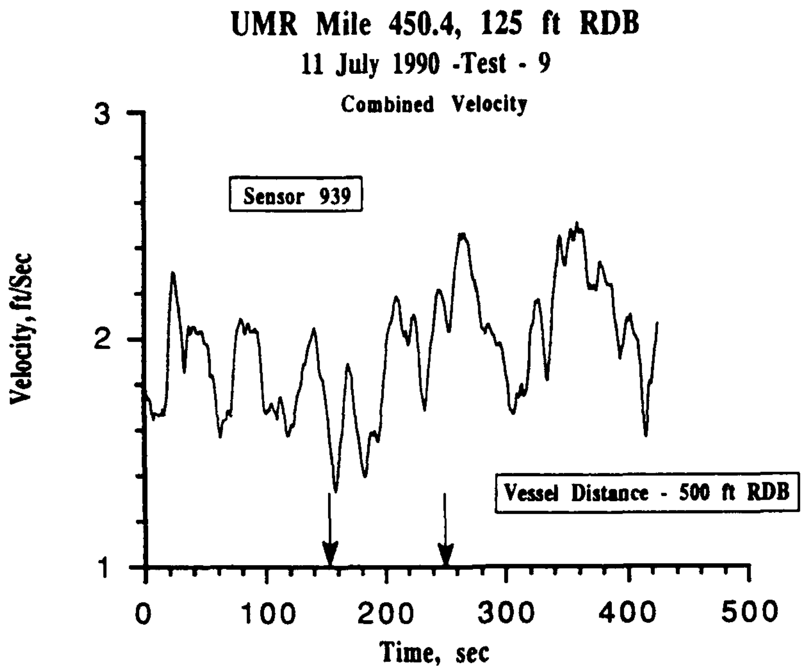

UMR Mile 450.4, 375 ft RDB
11 July 1990 - Test 9
Sensor 940
Vessel Distance - 500 ft RDB
Y
X
Velocity, ft/Sec
Time, sec
2.5
2
1.5
1
0.5
0
100
200
300
400
500

Figure E25


UMR Mile 450.4, 125 ft RDB
11 July 1990 -Test - 9
Combined Velocity
Sensor 939
Vessel Distance - 500 ft RDB
Velocity, ft/Sec
Time, sec
3
2
1
0
100
200
300
400
500

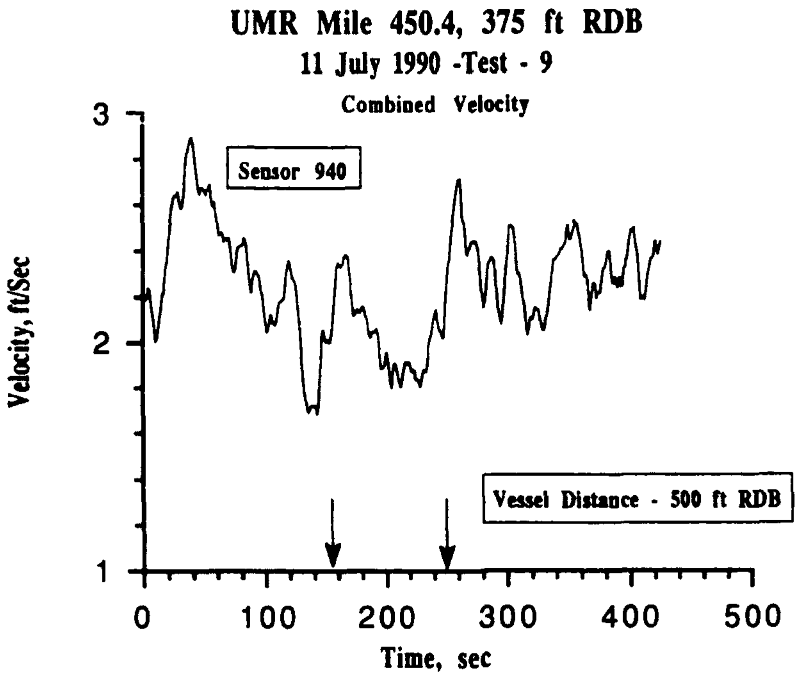
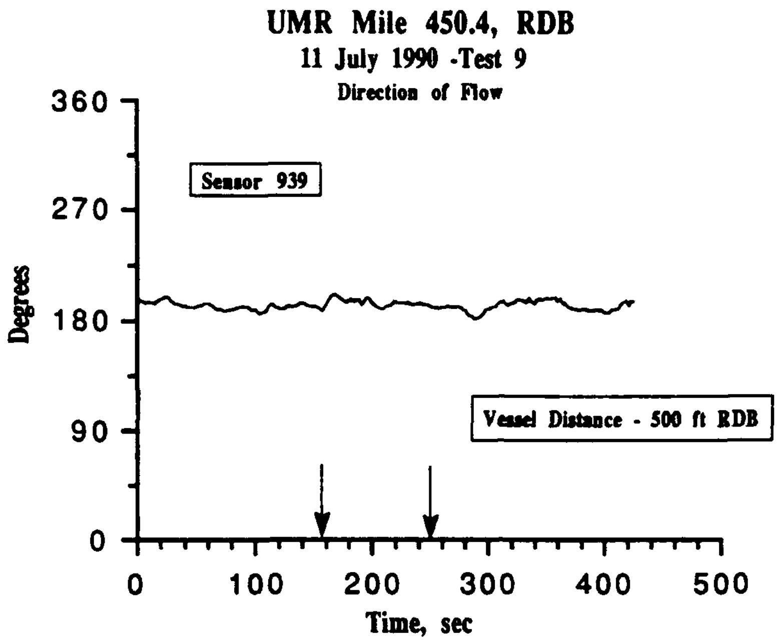
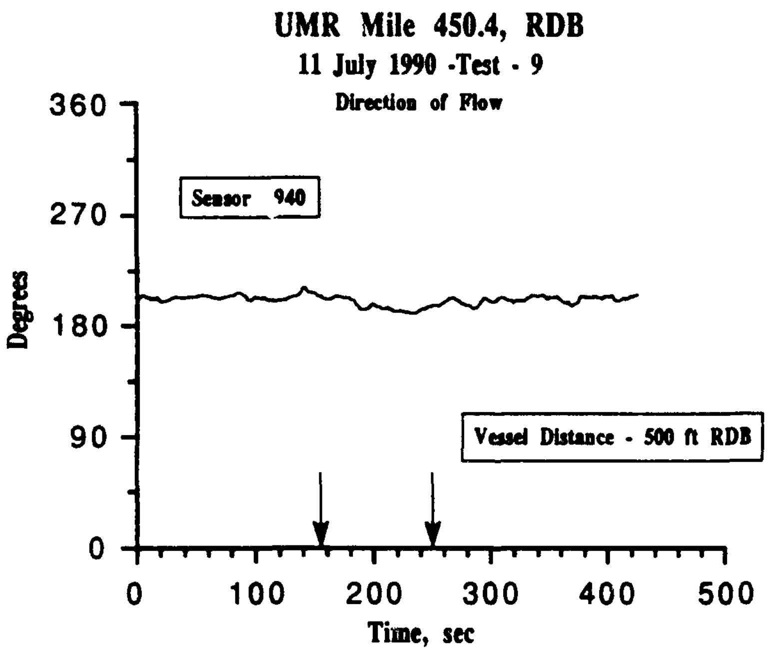

UMR Mile 450.4, 375 ft RDB
11 July 1990 -Test - 9
Combined Velocity
Sensor 940
Vessel Distance - 500 ft RDB
Velocity, ft/Sec
Time, sec
3
2
1
0
100
200
300
400
500

Figure E26

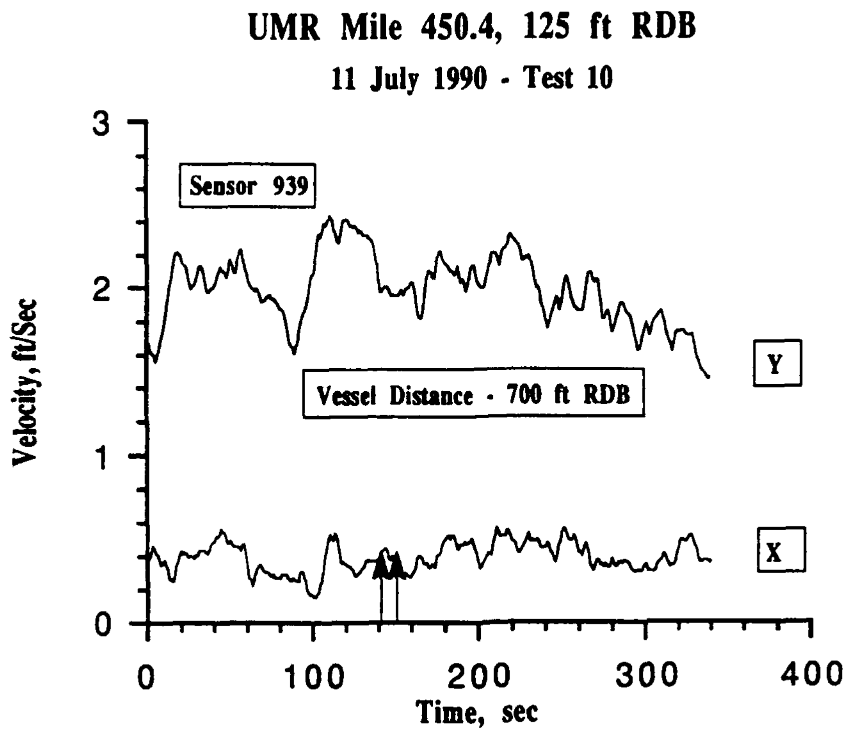


UMR Mile 450.4, RDB
11 July 1990 -Test 9
Direction of Flow
Sensor 939
Vessel Distance - 500 ft RDB
Degrees
360
270
180
90
0
0
100
200
300
400
500
Time, sec



UMR Mile 450.4, RDB
11 July 1990 -Test - 9
Direction of Flow
Sensor 940
Vessel Distance - 500 ft RDB
Degrees
360
270
180
90
0
0
100
200
300
400
500
Time, sec

Figure E27


UMR Mile 450.4, 125 ft RDB
11 July 1990 - Test 10
Sensor 939
Vessel Distance - 700 ft RDB
Y
X
Velocity, ft/Sec
Time, sec
0
1
2
3
0
100
200
300
400

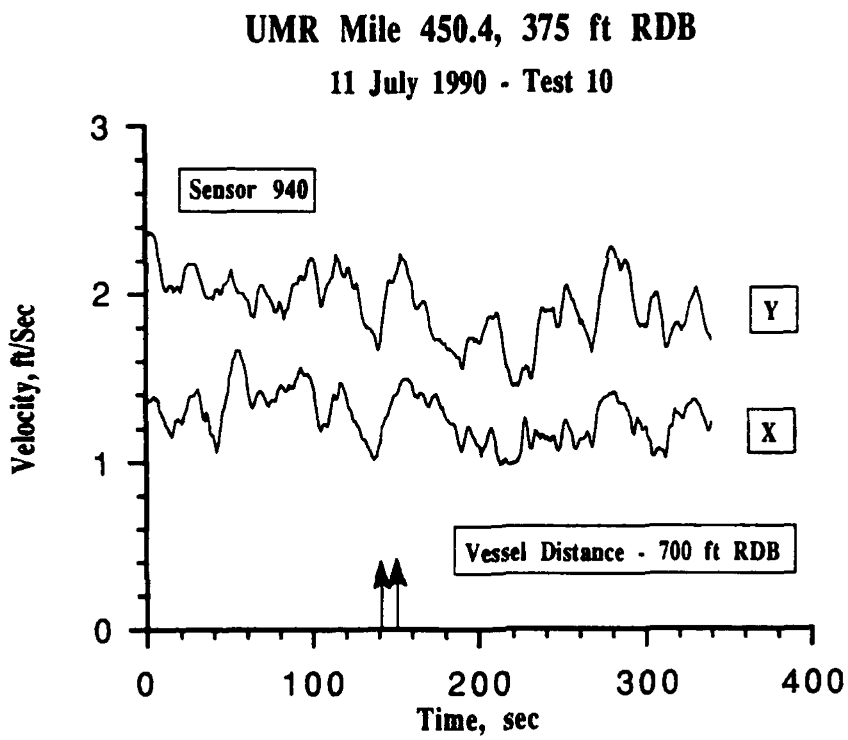
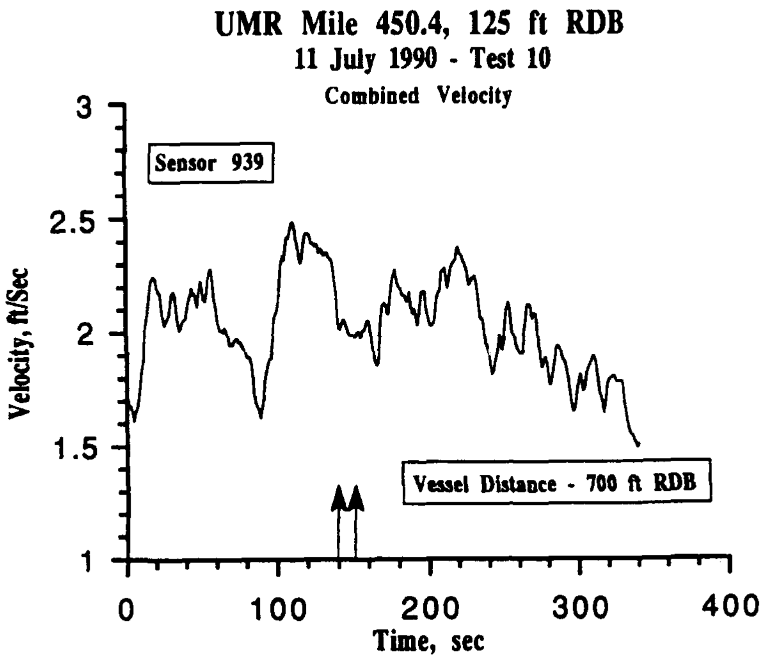

UMR Mile 450.4, 375 ft RDB
11 July 1990 - Test 10
Sensor 940
Y
X
Vessel Distance - 700 ft RDB
Velocity, ft/Sec
Time, sec
0
1
2
3
0
100
200
300
400

Figure E28


UMR Mile 450.4, 125 ft RDB
11 July 1990 - Test 10
Combined Velocity
Sensor 939
Vessel Distance - 700 ft RDB
Velocity, ft/Sec
Time, sec
3
2.5
2
1.5
1
0
100
200
300
400

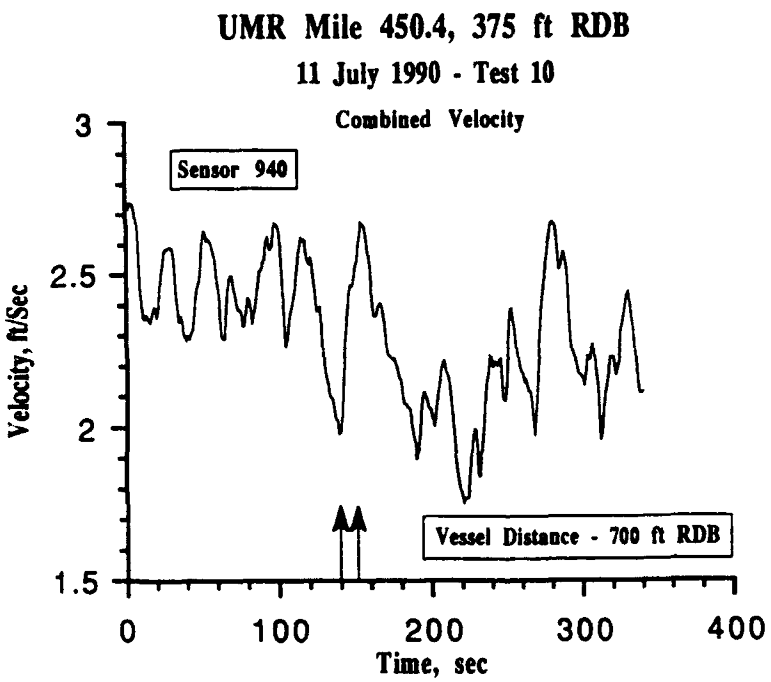
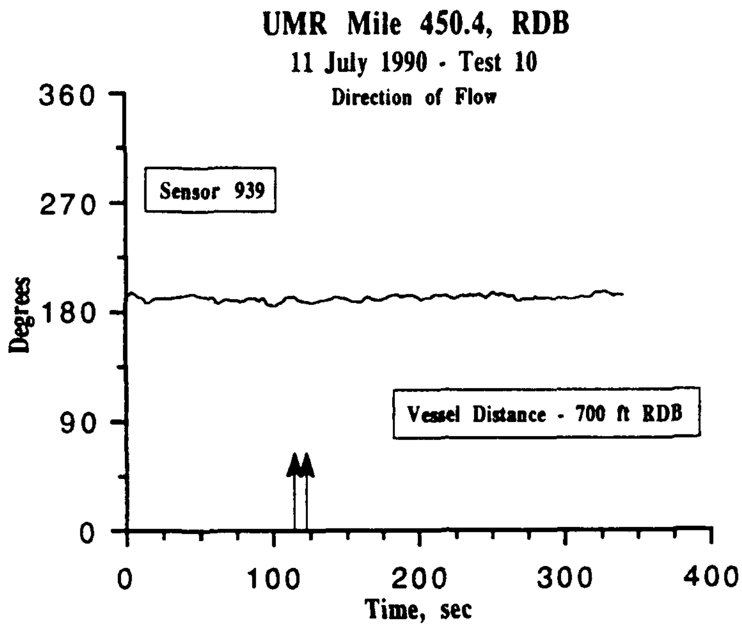

UMR Mile 450.4, 375 ft RDB
11 July 1990 - Test 10
Combined Velocity
Sensor 940
Vessel Distance - 700 ft RDB
Velocity, ft/Sec
Time, sec
3
2.5
2
1.5
0
100
200
300
400

Figure E29


UMR Mile 450.4, RDB
11 July 1990 - Test 10
Direction of Flow
Sensor 939
Vessel Distance - 700 ft RDB
Degrees
360
270
180
90
0
0
100
200
300
400
Time, sec

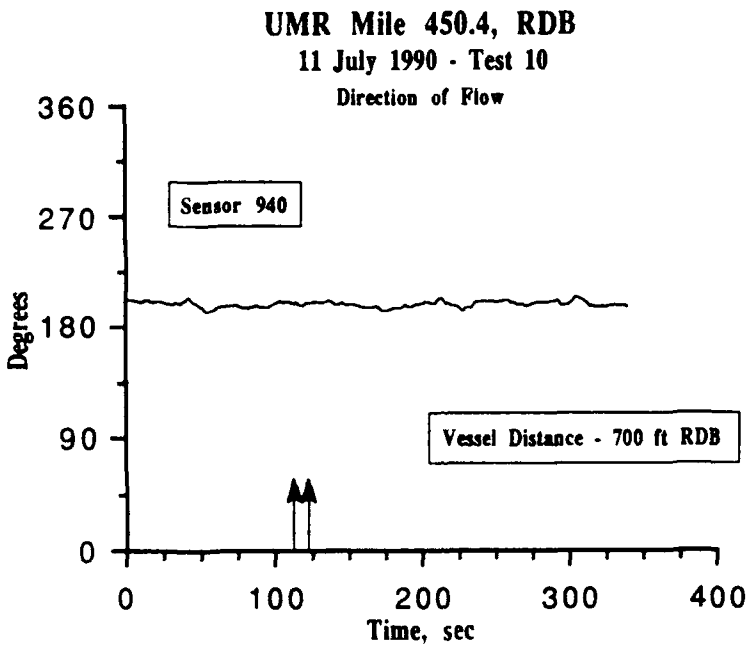
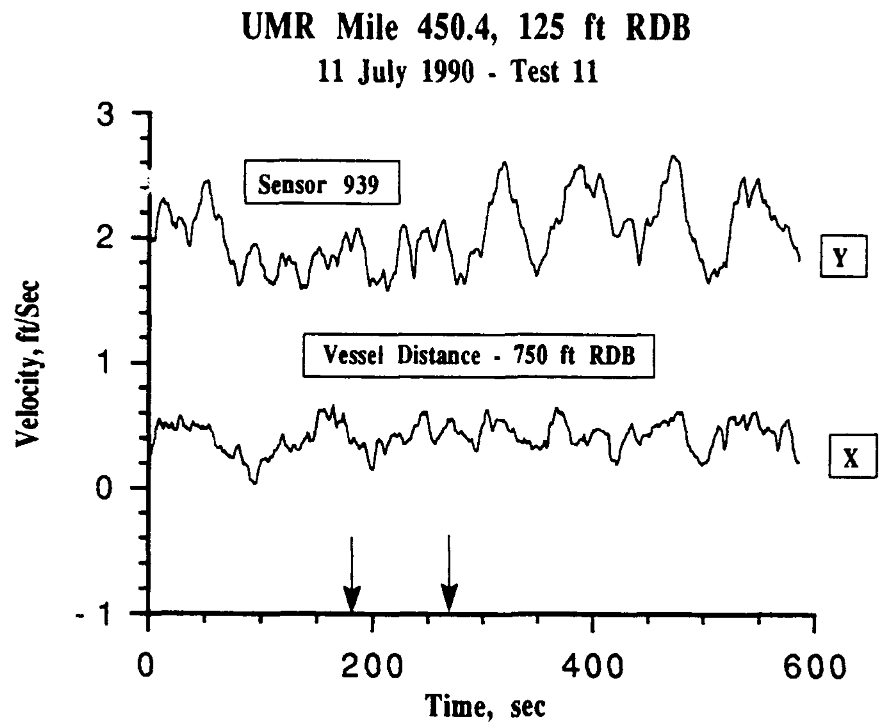

UMR Mile 450.4, RDB
11 July 1990 - Test 10
Direction of Flow
Sensor 940
Vessel Distance - 700 ft RDB
Degrees
360
270
180
90
0
0
100
200
300
400
Time, sec

Figure E30


UMR Mile 450.4, 125 ft RDB
11 July 1990 - Test 11
Sensor 939
Vessel Distance - 750 ft RDB
Y
X
Velocity, ft/Sec
Time, sec
3
2
1
0
- 1
0
200
400
600

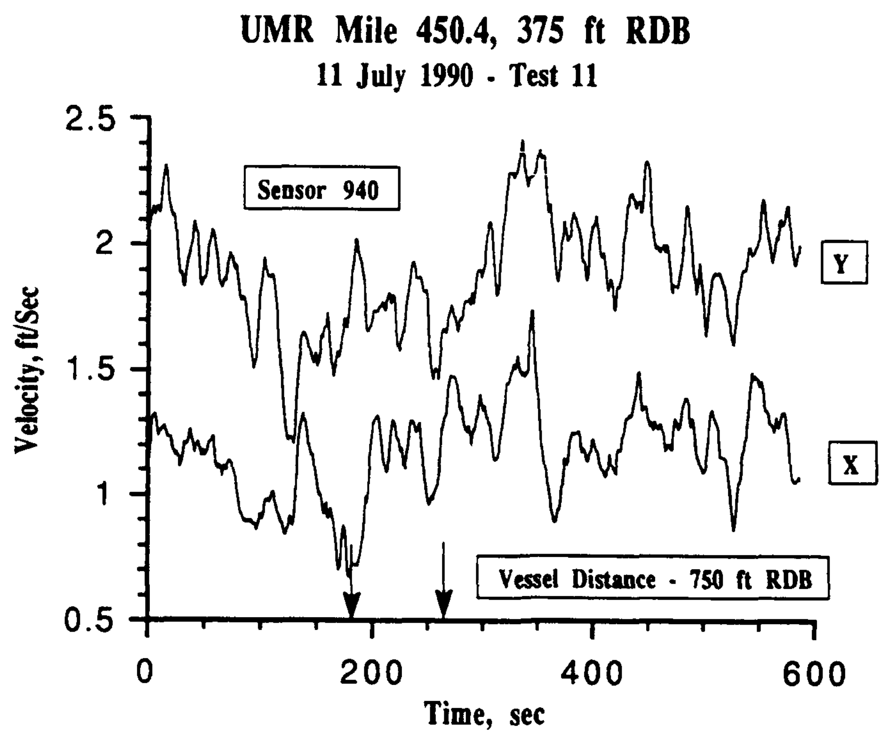
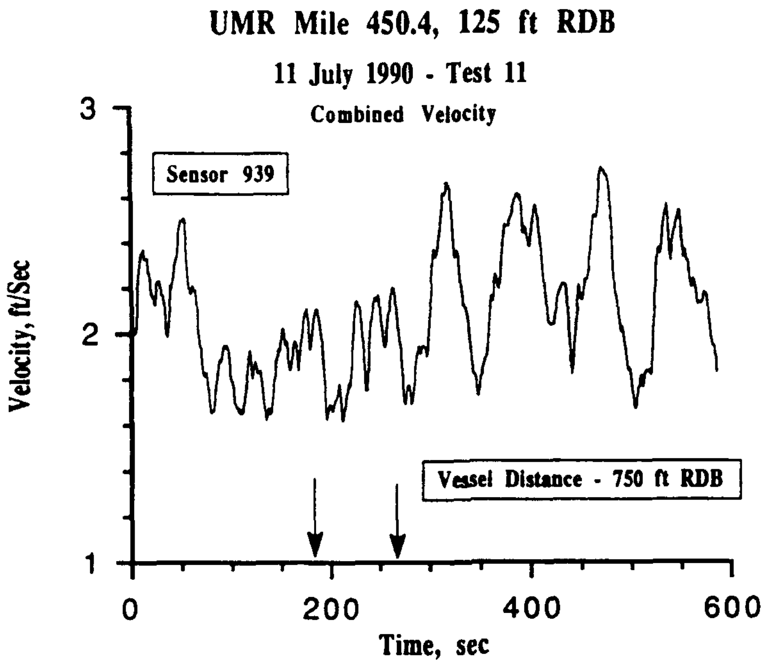

UMR Mile 450.4, 375 ft RDB
11 July 1990 - Test 11
Sensor 940
Vessel Distance - 750 ft RDB
Y
X
Velocity, ft/Sec
Time, sec
2.5
2
1.5
1
0.5
0
200
400
600

Figure E31


UMR Mile 450.4, 125 ft RDB
11 July 1990 - Test 11
Combined Velocity
Sensor 939
Vessel Distance - 750 ft RDB
Velocity, ft/Sec
Time, sec
3
2
1
0
200
400
600

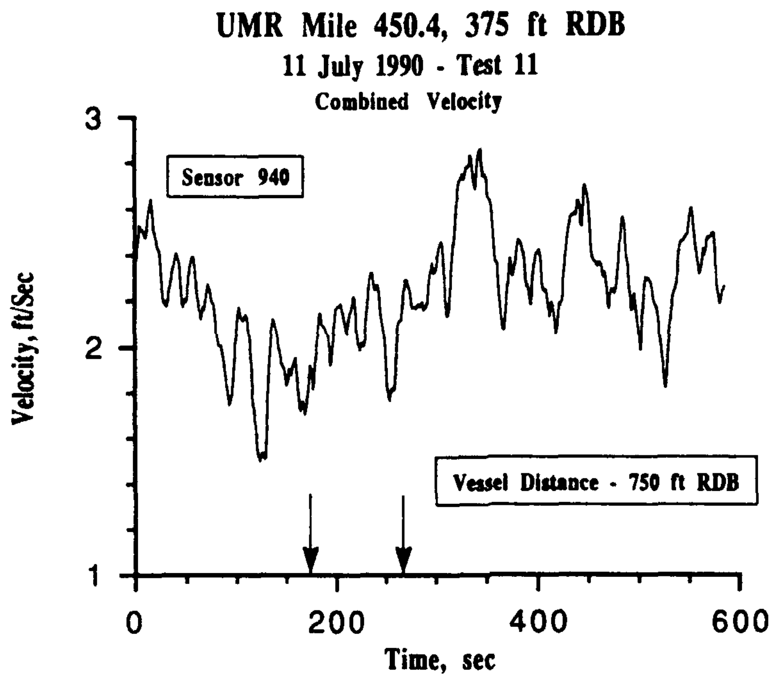
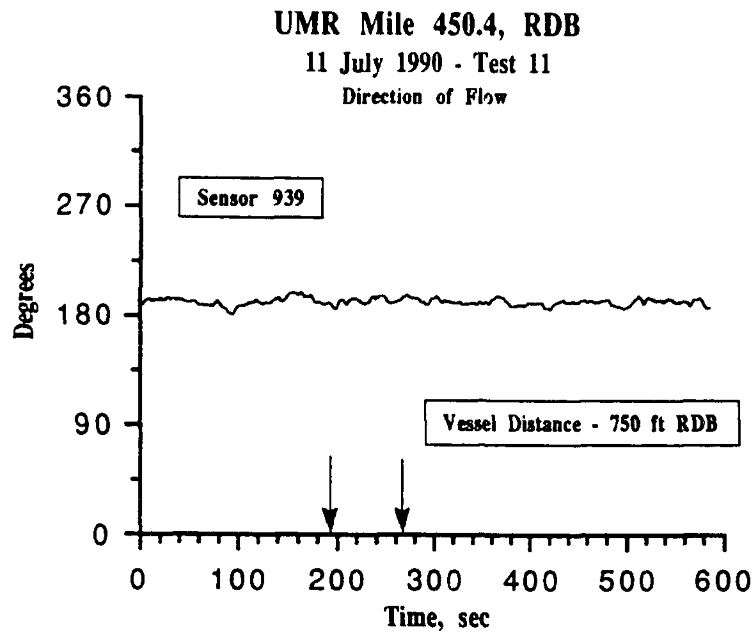

UMR Mile 450.4, 375 ft RDB
11 July 1990 - Test 11
Combined Velocity
Sensor 940
Vessel Distance - 750 ft RDB
Velocity, ft/Sec
Time, sec
3
2
1
0
200
400
600

Figure E32


UMR Mile 450.4, RDB
11 July 1990 - Test 11
Direction of Flow
Sensor 939
Vessel Distance - 750 ft RDB
Degrees
360
270
180
90
0
0
100
200
300
400
500
600
Time, sec

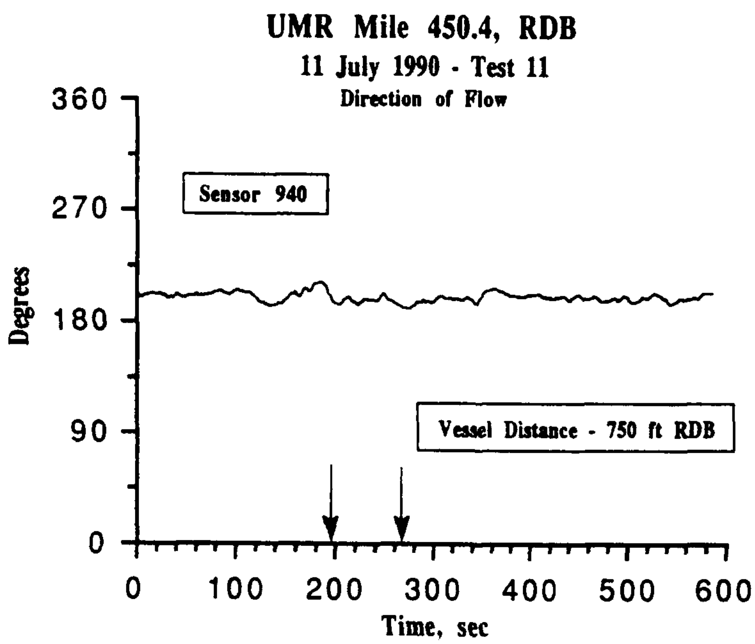
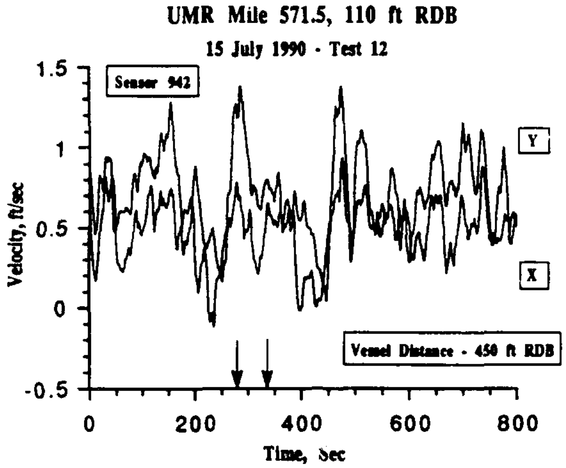
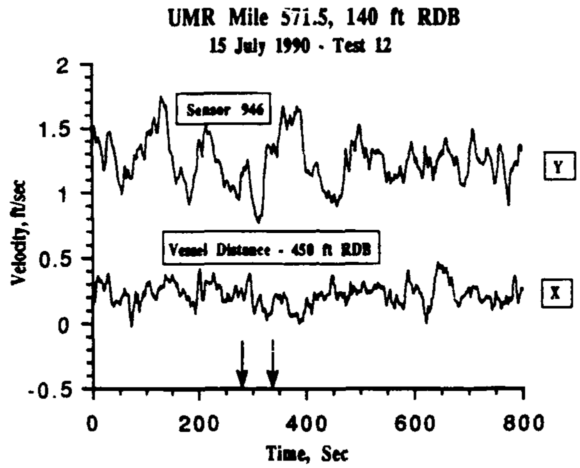

UMR Mile 450.4, RDB
11 July 1990 - Test 11
Direction of Flow
Sensor 940
Vessel Distance - 750 ft RDB
Degrees
360
270
180
90
0
0
100
200
300
400
500
600
Time, sec

Figure E33


UMR Mile 571.5, 110 ft RDB
15 July 1990 - Test 12
Sensor 942
Y
X
Vessel Distance - 450 ft RDB
Velocity, ft/sec
Time, sec
1.5
1
0.5
0
-0.5
0
200
400
600
800


UMR Mile 571.5, 140 ft RDB
15 July 1990 - Test 12
Sensor 946
Y
X
Vessel Distance - 450 ft RDB
Velocity, ft/sec
Time, Sec
2
1.5
1
0.5
0
-0.5
0
200
400
600
800

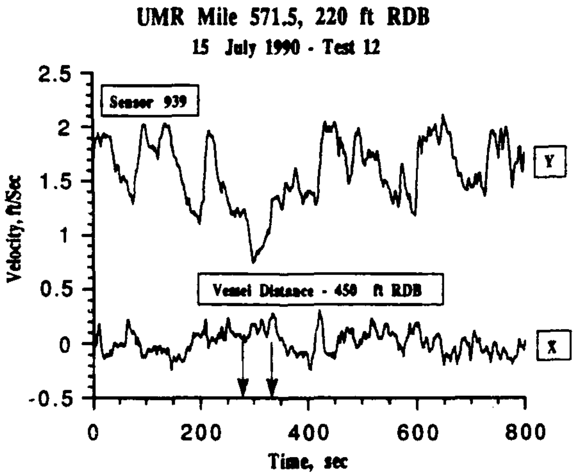
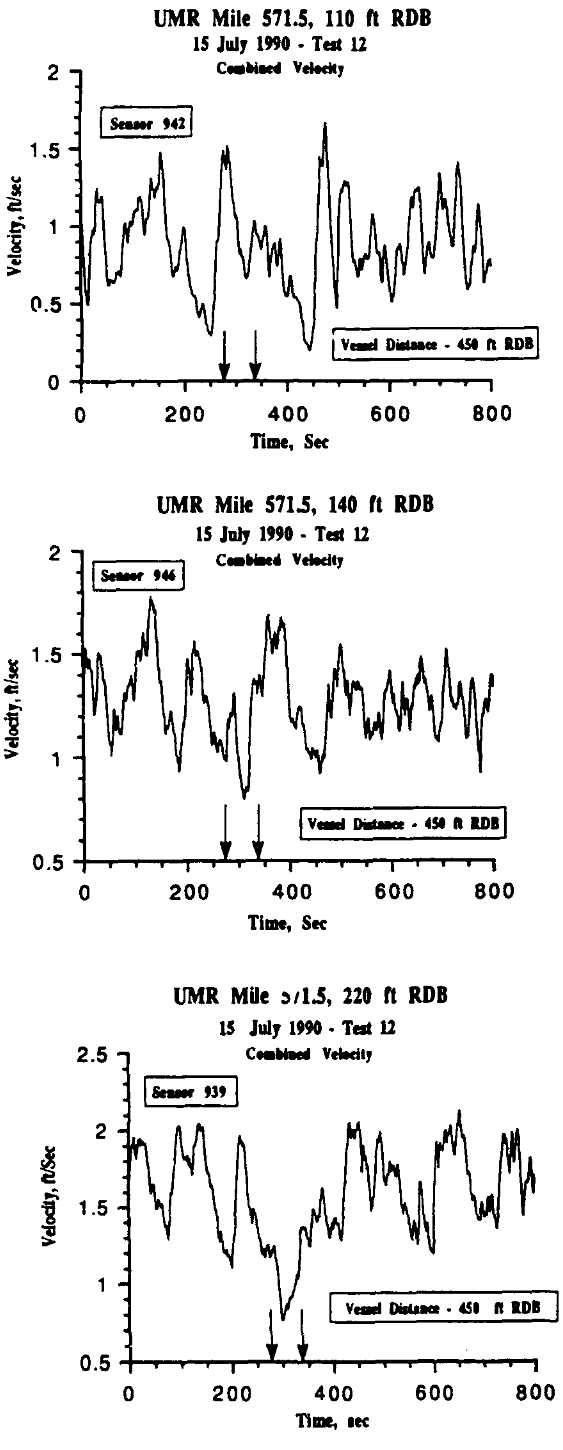
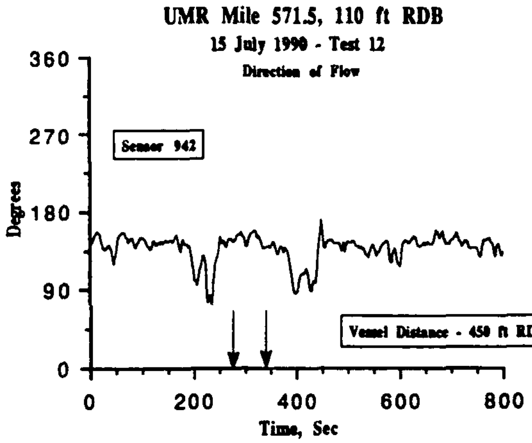

UMR Mile 571.5, 220 ft RDB
15 July 1990 - Test 12
Sensor 939
Y
X
Vessel Distance - 450 ft RDB
Velocity, ft/Sec
Time, sec
2.5
2
1.5
1
0.5
0
-0.5
0
200
400
600
800

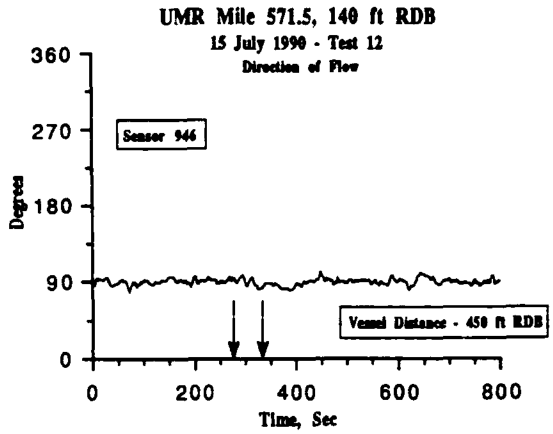
Figure E34



UMR Mile 571.5, 110 ft RDB
15 July 1990 - Test 12
Combined Velocity
Sensor 942
Velocity, ft/sec
Vessel Distance - 450 ft RDB
Time, Sec
UMR Mile 571.5, 140 ft RDB
15 July 1990 - Test 12
Combined Velocity
Sensor 946
Velocity, ft/sec
Vessel Distance - 450 ft RDB
Time, Sec
UMR Mile 5/1.5, 220 ft RDB
15 July 1990 - Test 12
Combined Velocity
Sensor 939
Velocity, ft/Sec
Vessel Distance - 450 ft RDB
Time, sec

Figure E35


UMR Mile 571.5, 110 ft RDB
15 July 1990 - Test 12
Direction of Flow
Sensor 942
Vessel Distance - 450 ft RDB
Degrees
360
270
180
90
0
0
200
400
600
800
Time, Sec


UMR Mile 571.5, 140 ft RDB
15 July 1990 - Test 12
Direction of Flow
Sensor 946
Vessel Distance - 450 ft RDB
Degrees
360
270
180
90
0
0
200
400
600
800
Time, Sec

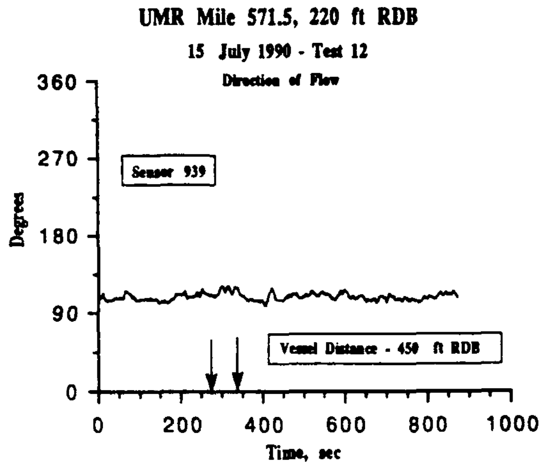

UMR Mile 571.5, 220 ft RDB
15 July 1990 - Test 12
Direction of Flow
Sensor 939
Vessel Distance - 450 ft RDB
Degrees
360
270
180
90
0
0
200
400
600
800
1000
Time, sec

Figure E36

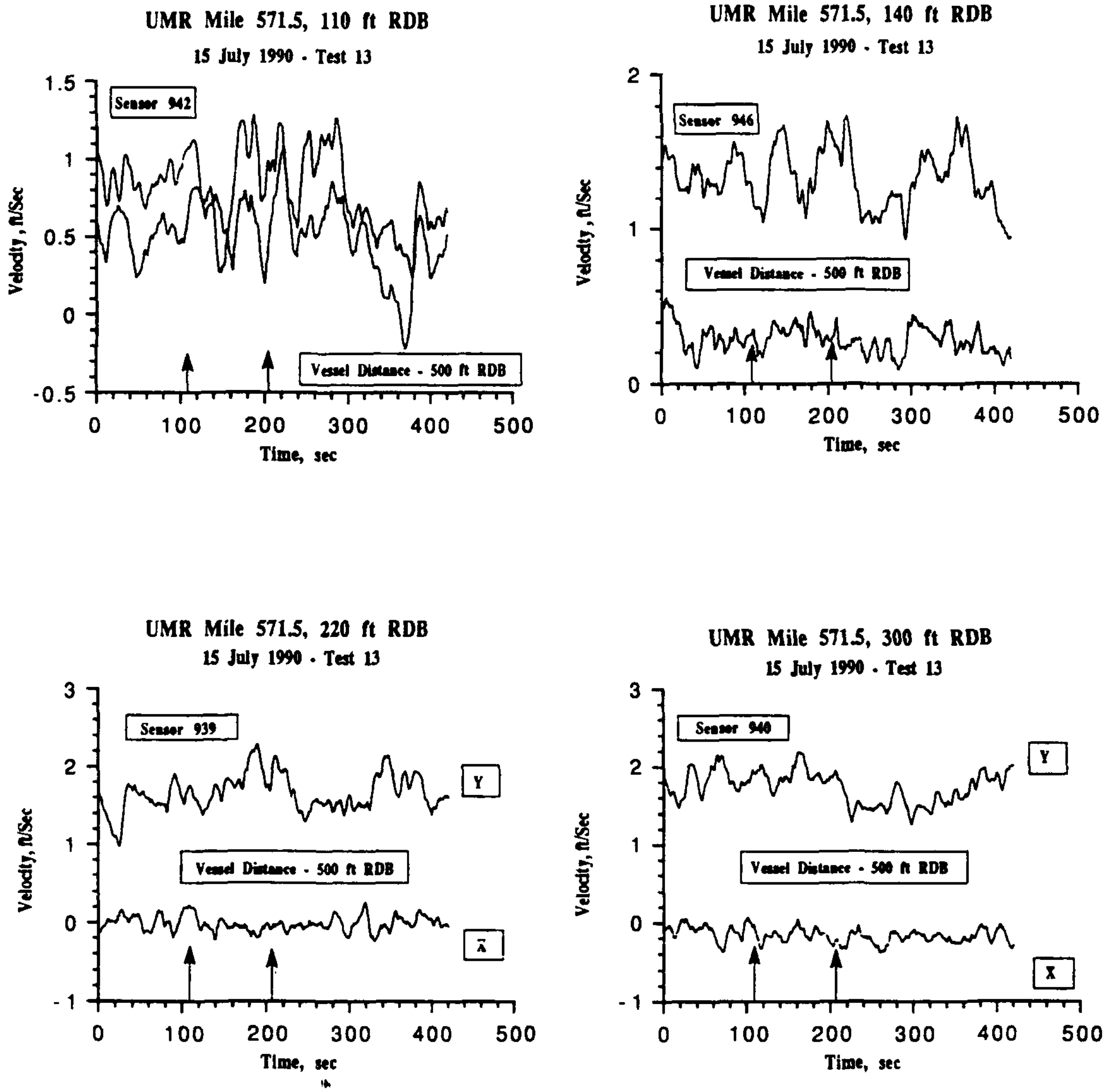

UMR Mile 571.5, 110 ft RDB
15 July 1990 - Test 13
Sensor 942
Vessel Distance - 500 ft RDB
Velocity, ft/Sec
Time, sec
UMR Mile 571.5, 140 ft RDB
15 July 1990 - Test 13
Sensor 946
Vessel Distance - 500 ft RDB
Velocity, ft/Sec
Time, sec
UMR Mile 571.5, 220 ft RDB
15 July 1990 - Test 13
Sensor 939
Vessel Distance - 500 ft RDB
Y
X
Velocity, ft/Sec
Time, sec
UMR Mile 571.5, 300 ft RDB
15 July 1990 - Test 13
Sensor 940
Vessel Distance - 500 ft RDB
Y
X
Velocity, ft/Sec
Time, sec

Figure E37

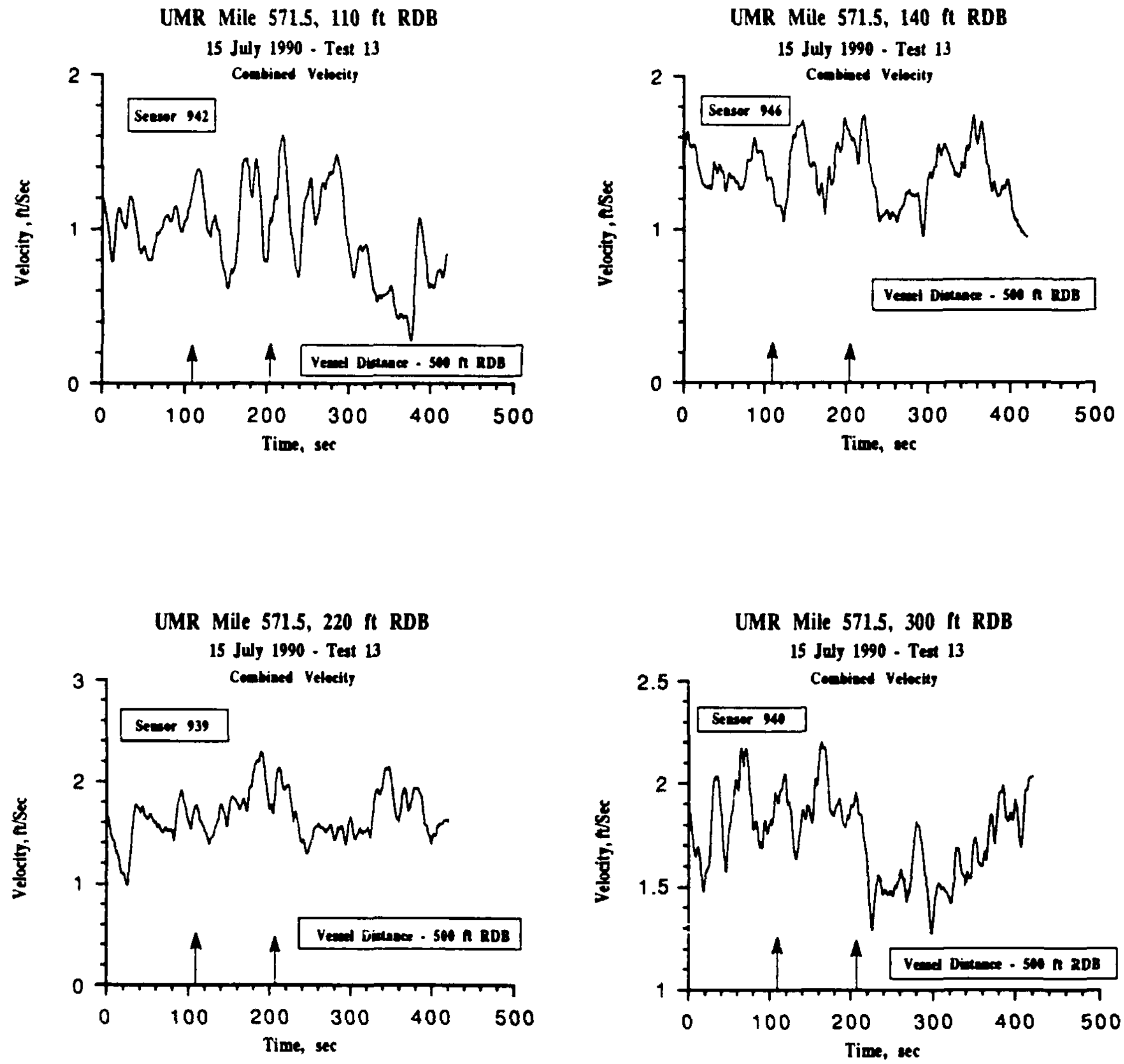
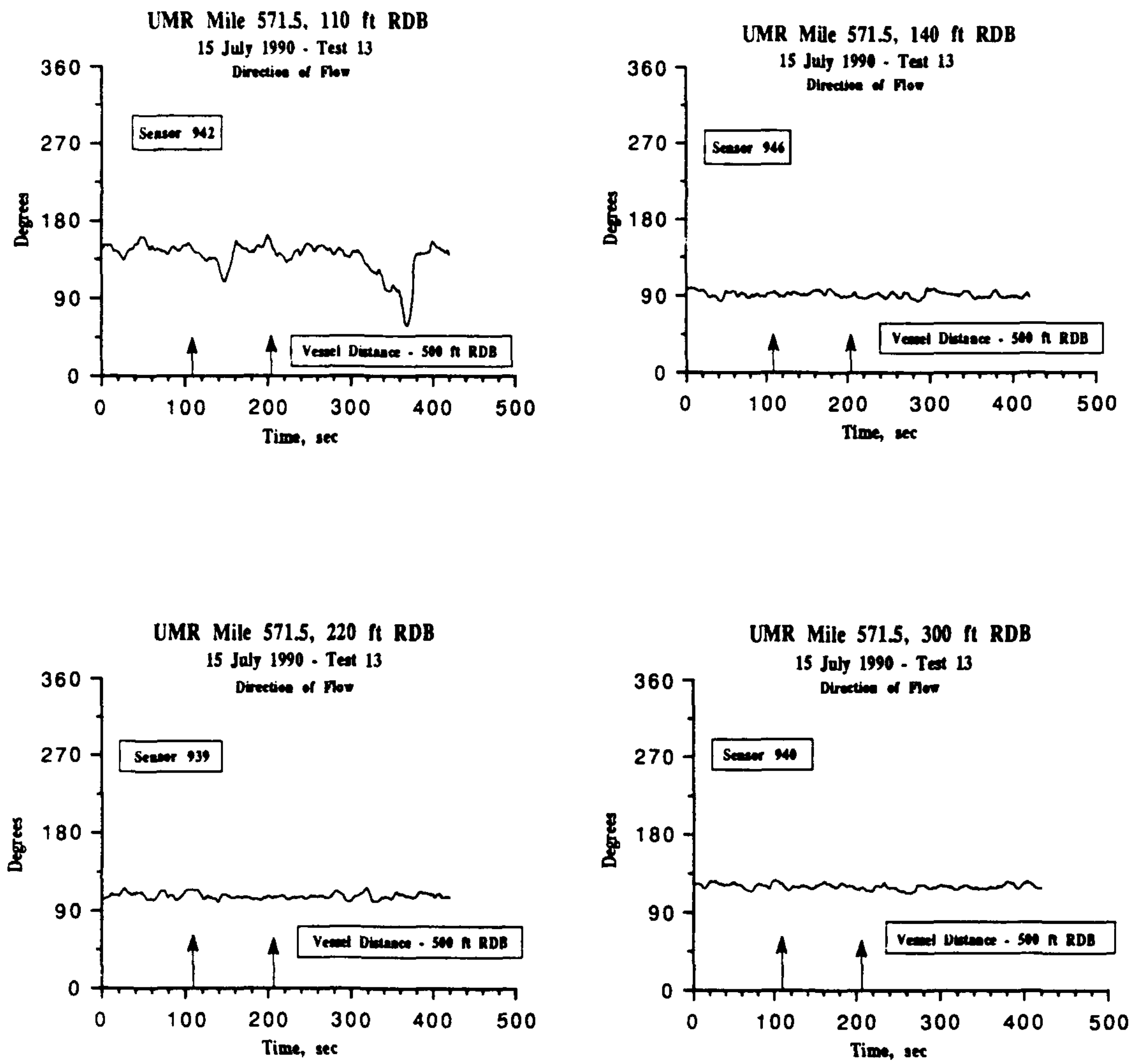

UMR Mile 571.5, 110 ft RDB
15 July 1990 - Test 13
Combined Velocity
Sensor 942
Vessel Distance - 500 ft RDB
Velocity, ft/Sec
Time, sec
UMR Mile 571.5, 140 ft RDB
15 July 1990 - Test 13
Combined Velocity
Sensor 946
Vessel Distance - 500 ft RDB
Velocity, ft/Sec
Time, sec
UMR Mile 571.5, 220 ft RDB
15 July 1990 - Test 13
Combined Velocity
Sensor 939
Vessel Distance - 500 ft RDB
Velocity, ft/Sec
Time, sec
UMR Mile 571.5, 300 ft RDB
15 July 1990 - Test 13
Combined Velocity
Sensor 940
Vessel Distance - 500 ft RDB
Velocity, ft/Sec
Time, sec

Figure E38



UMR Mile 571.5, 110 ft RDB
15 July 1990 - Test 13
Direction of Flow
Sensor 942
Vessel Distance - 500 ft RDB
Degrees
Time, sec
UMR Mile 571.5, 140 ft RDB
15 July 1990 - Test 13
Direction of Flow
Sensor 946
Vessel Distance - 500 ft RDB
Degrees
Time, sec
UMR Mile 571.5, 220 ft RDB
15 July 1990 - Test 13
Direction of Flow
Sensor 939
Vessel Distance - 500 ft RDB
Degrees
Time, sec
UMR Mile 571.5, 300 ft RDB
15 July 1990 - Test 13
Direction of Flow
Sensor 940
Vessel Distance - 500 ft RDB
Degrees
Time, sec

Figure E39

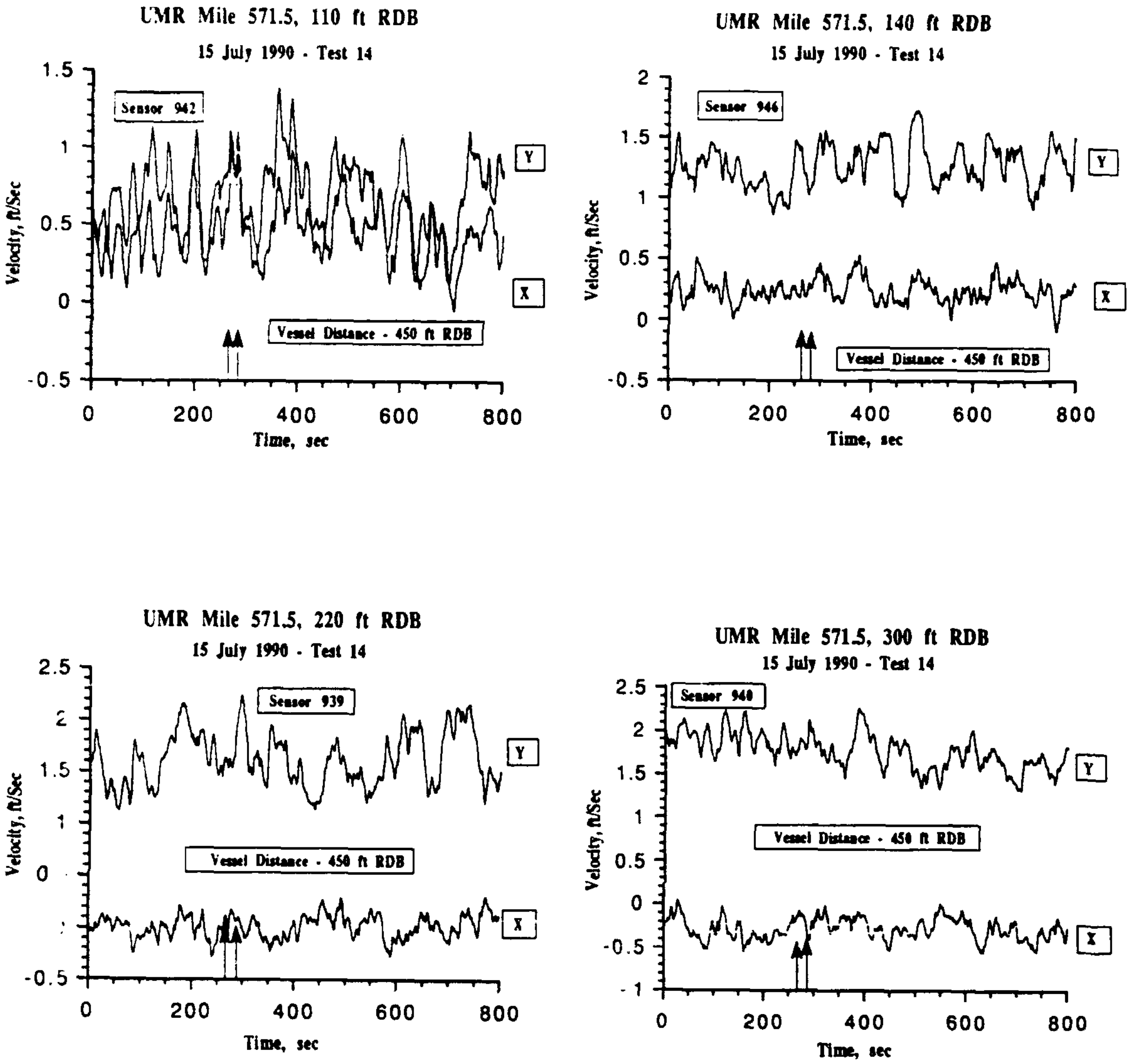
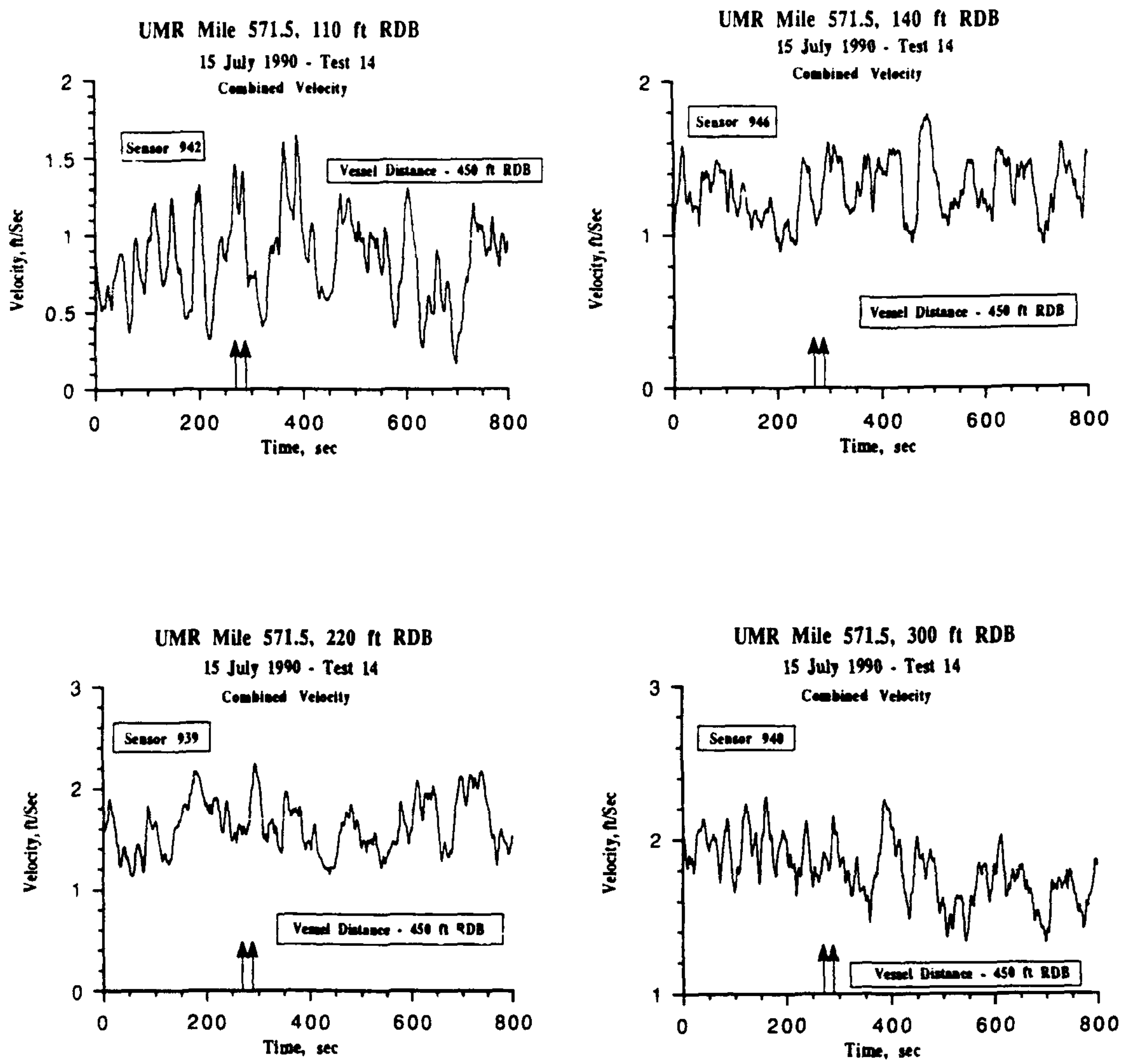

UMR Mile 571.5, 110 ft RDB
15 July 1990 - Test 14
Sensor 942
Vessel Distance - 450 ft RDB
Y
X
Velocity, ft/Sec
Time, sec
UMR Mile 571.5, 140 ft RDB
15 July 1990 - Test 14
Sensor 946
Vessel Distance - 450 ft RDB
Y
X
Velocity, ft/Sec
Time, sec
UMR Mile 571.5, 220 ft RDB
15 July 1990 - Test 14
Sensor 939
Vessel Distance - 450 ft RDB
Y
X
Velocity, ft/Sec
Time, sec
UMR Mile 571.5, 300 ft RDB
15 July 1990 - Test 14
Sensor 940
Vessel Distance - 450 ft RDB
Y
X
Velocity, ft/Sec
Time, sec

Figure E40



UMR Mile 571.5, 110 ft RDB
15 July 1990 - Test 14
Combined Velocity
Sensor 942
Vessel Distance - 450 ft RDB
Velocity, ft/Sec
Time, sec
UMR Mile 571.5, 140 ft RDB
15 July 1990 - Test 14
Combined Velocity
Sensor 946
Vessel Distance - 450 ft RDB
Velocity, ft/Sec
Time, sec
UMR Mile 571.5, 220 ft RDB
15 July 1990 - Test 14
Combined Velocity
Sensor 939
Vessel Distance - 450 ft RDB
Velocity, ft/Sec
Time, sec
UMR Mile 571.5, 300 ft RDB
15 July 1990 - Test 14
Combined Velocity
Sensor 940
Vessel Distance - 450 ft RDB
Velocity, ft/Sec
Time, sec

Figure E41

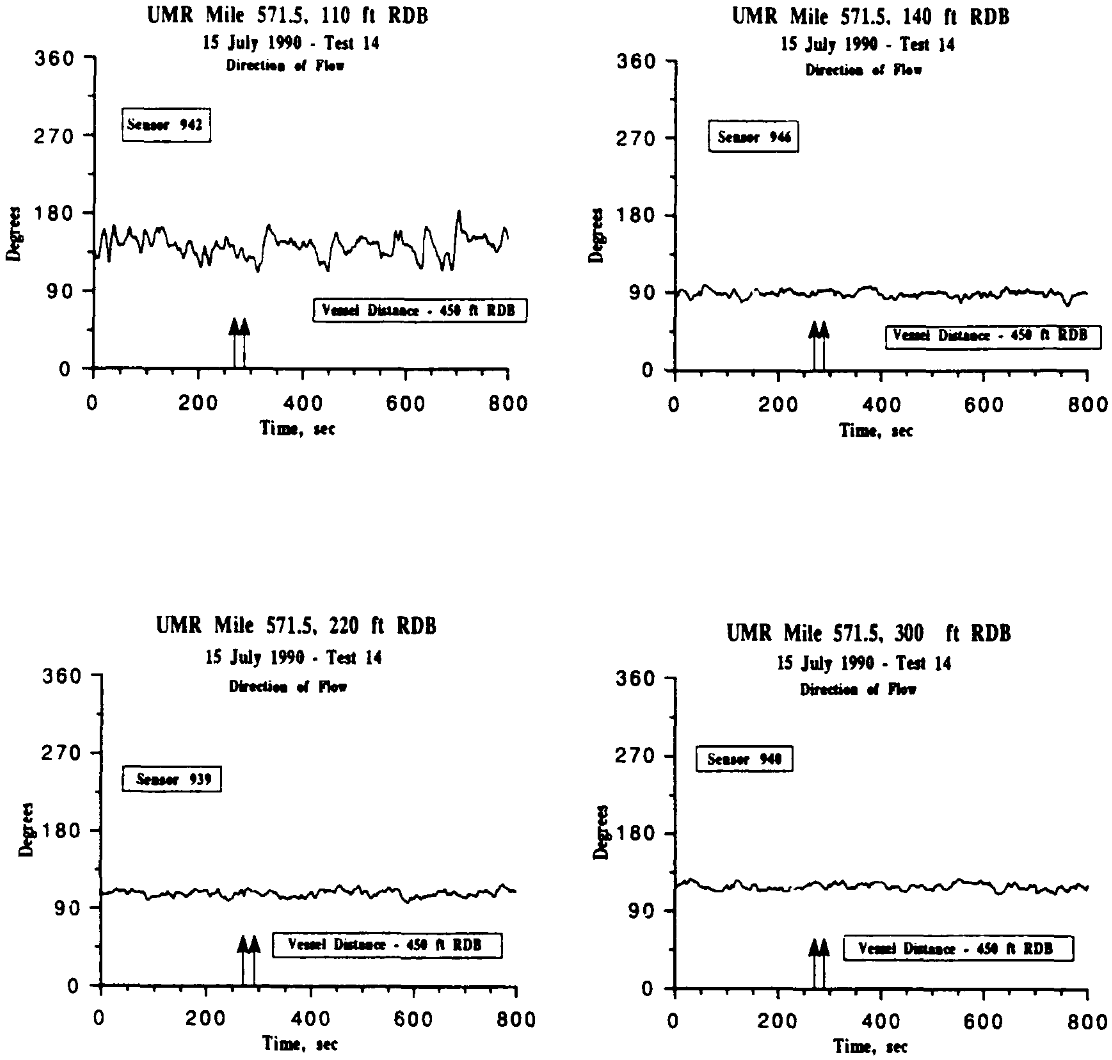

UMR Mile 571.5, 110 ft RDB
15 July 1990 - Test 14
Direction of Flow
Sensor 942
Vessel Distance - 450 ft RDB
Degrees
Time, sec
0
90
180
270
360
0
200
400
600
800
UMR Mile 571.5, 140 ft RDB
15 July 1990 - Test 14
Direction of Flow
Sensor 946
Vessel Distance - 450 ft RDB
UMR Mile 571.5, 220 ft RDB
15 July 1990 - Test 14
Direction of Flow
Sensor 939
Vessel Distance - 450 ft RDB
UMR Mile 571.5, 300 ft RDB
15 July 1990 - Test 14
Direction of Flow
Sensor 940
Vessel Distance - 450 ft RDB

Figure E42

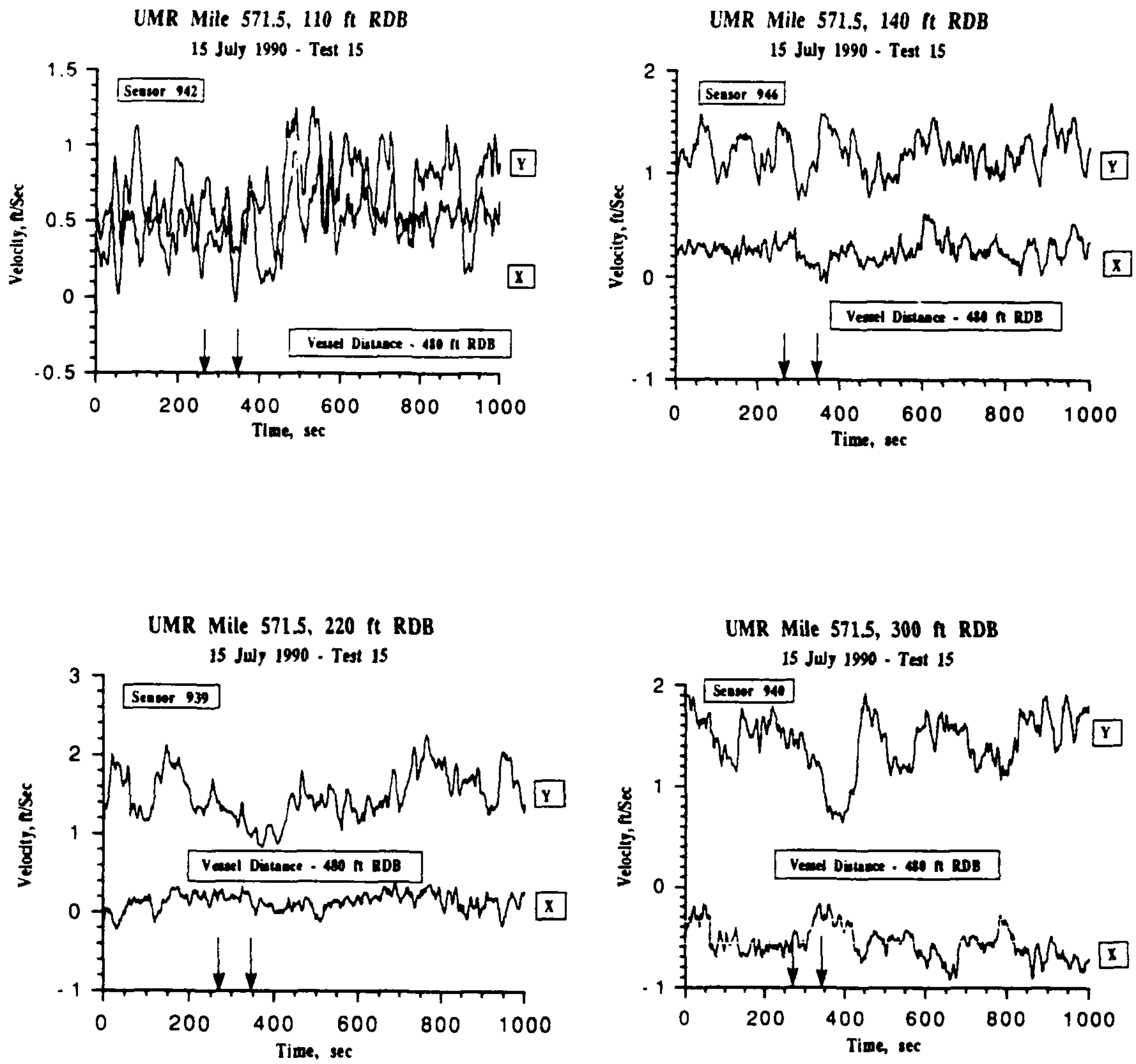

UMR Mile 571.5, 110 ft RDB
15 July 1990 - Test 15
Sensor 942
Vessel Distance - 480 ft RDB
Velocity, ft/Sec
Time, sec
Y
X
UMR Mile 571.5, 140 ft RDB
15 July 1990 - Test 15
Sensor 946
Vessel Distance - 480 ft RDB
UMR Mile 571.5, 220 ft RDB
15 July 1990 - Test 15
Sensor 939
Vessel Distance - 480 ft RDB
UMR Mile 571.5, 300 ft RDB
15 July 1990 - Test 15
Sensor 940
Vessel Distance - 480 ft RDB

Figure E43

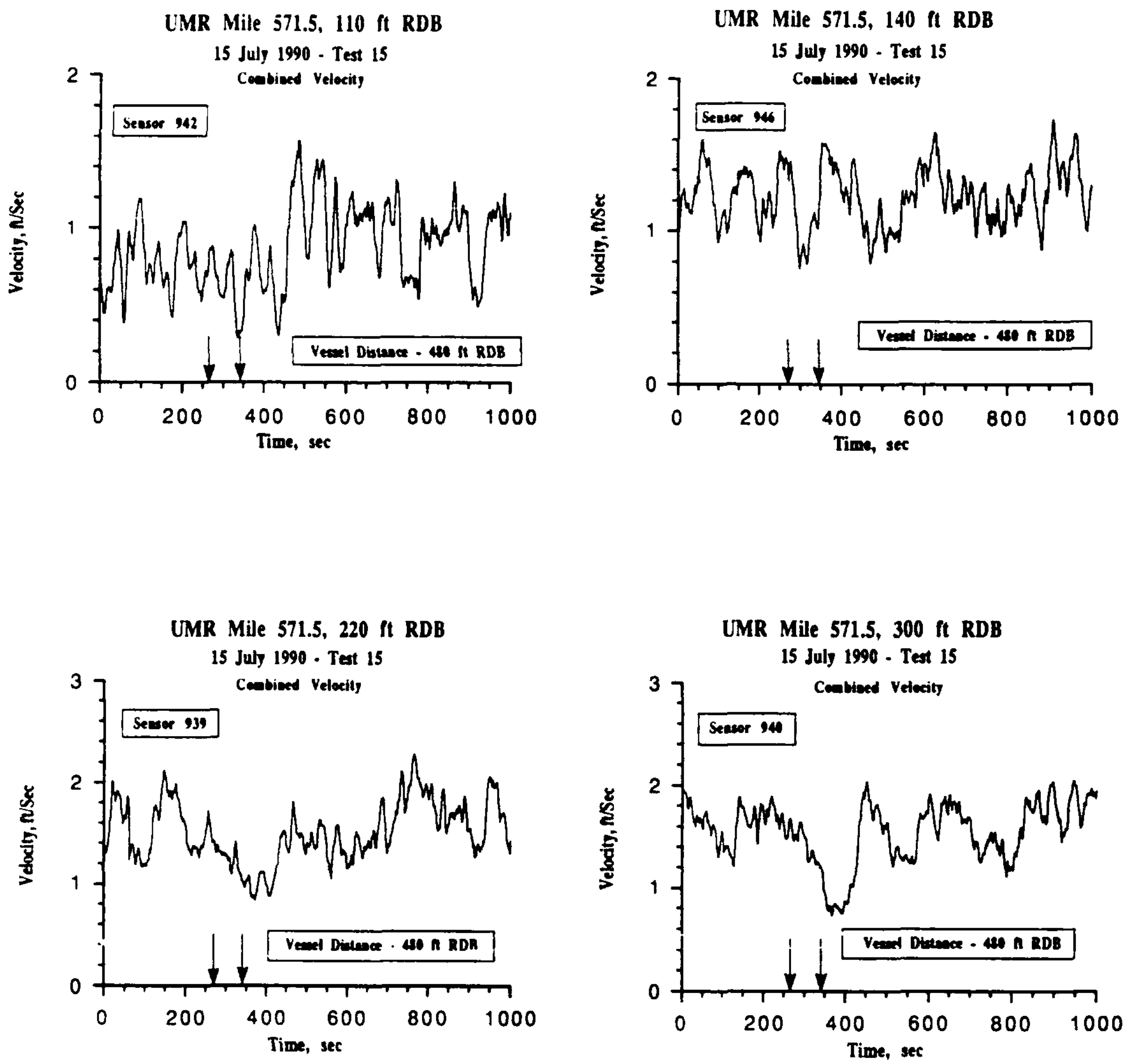
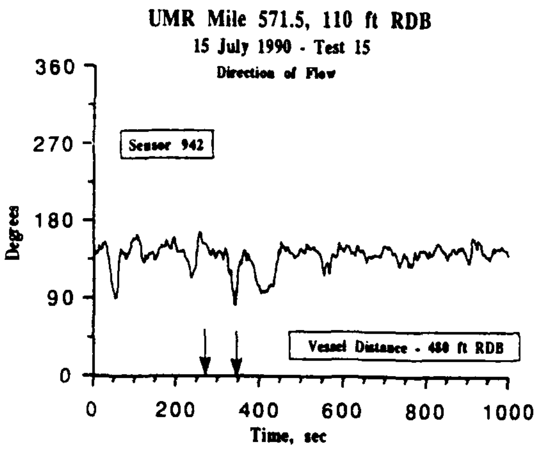
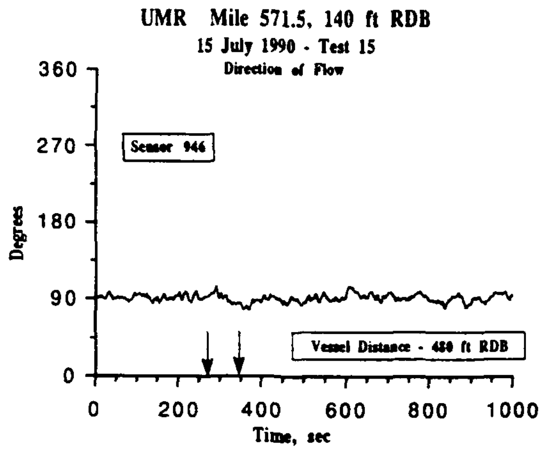
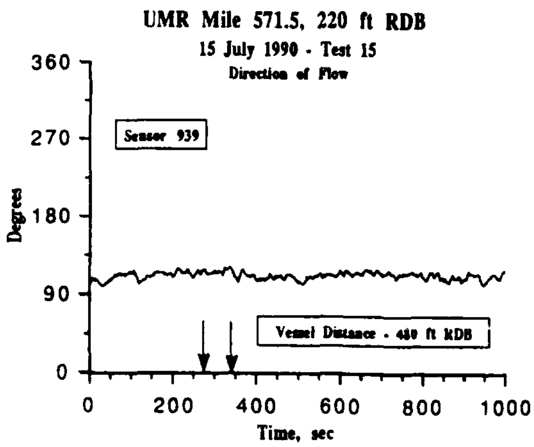

UMR Mile 571.5, 110 ft RDB
15 July 1990 - Test 15
Combined Velocity
Sensor 942
Vessel Distance - 480 ft RDB
Velocity, ft/Sec
Time, sec
UMR Mile 571.5, 140 ft RDB
15 July 1990 - Test 15
Combined Velocity
Sensor 946
Vessel Distance - 480 ft RDB
Velocity, ft/Sec
Time, sec
UMR Mile 571.5, 220 ft RDB
15 July 1990 - Test 15
Combined Velocity
Sensor 939
Vessel Distance - 480 ft RDB
Velocity, ft/Sec
Time, sec
UMR Mile 571.5, 300 ft RDB
15 July 1990 - Test 15
Combined Velocity
Sensor 940
Vessel Distance - 480 ft RDB
Velocity, ft/Sec
Time, sec

Figure E44


UMR Mile 571.5, 110 ft RDB
15 July 1990 - Test 15
Direction of Flow
Sensor 942
Vessel Distance - 480 ft RDB
Degrees
360
270
180
90
0
0
200
400
600
800
1000
Time, sec


UMR Mile 571.5, 140 ft RDB
15 July 1990 - Test 15
Direction of Flow
Sensor 946
Vessel Distance - 480 ft RDB
Degrees
360
270
180
90
0
0
200
400
600
800
1000
Time, sec


UMR Mile 571.5, 220 ft RDB
15 July 1990 - Test 15
Direction of Flow
Sensor 939
Vessel Distance - 480 ft RDB
Degrees
360
270
180
90
0
0
200
400
600
800
1000
Time, sec

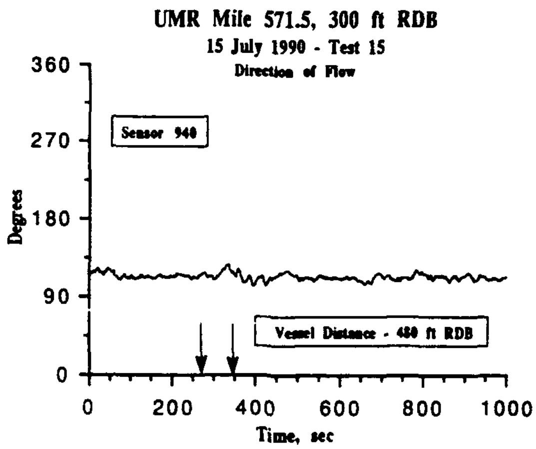
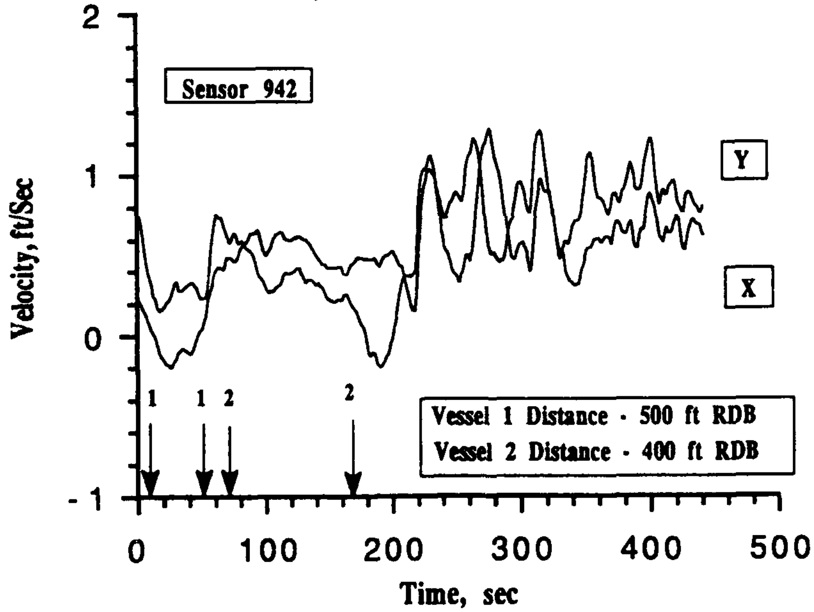

UMR Mile 571.5, 300 ft RDB
15 July 1990 - Test 15
Direction of Flow
Sensor 940
Vessel Distance - 480 ft RDB
Degrees
360
270
180
90
0
0
200
400
600
800
1000
Time, sec

Figure E45

UMR Mile 571.5, 110 ft RDB

15 July 1990 - Test 16 and 17



UMR Mile 571.5, 140 ft RDB

15 July 1990 - Test 16 and 17

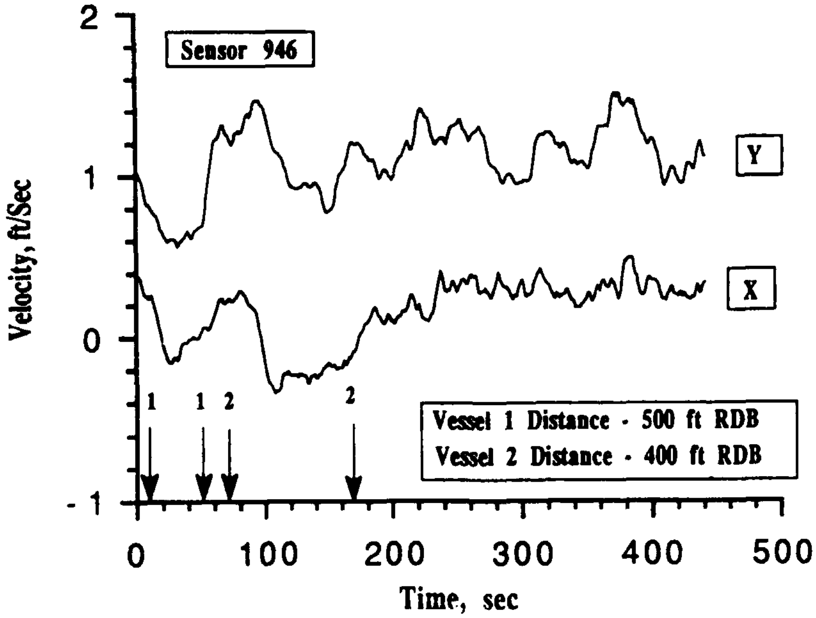
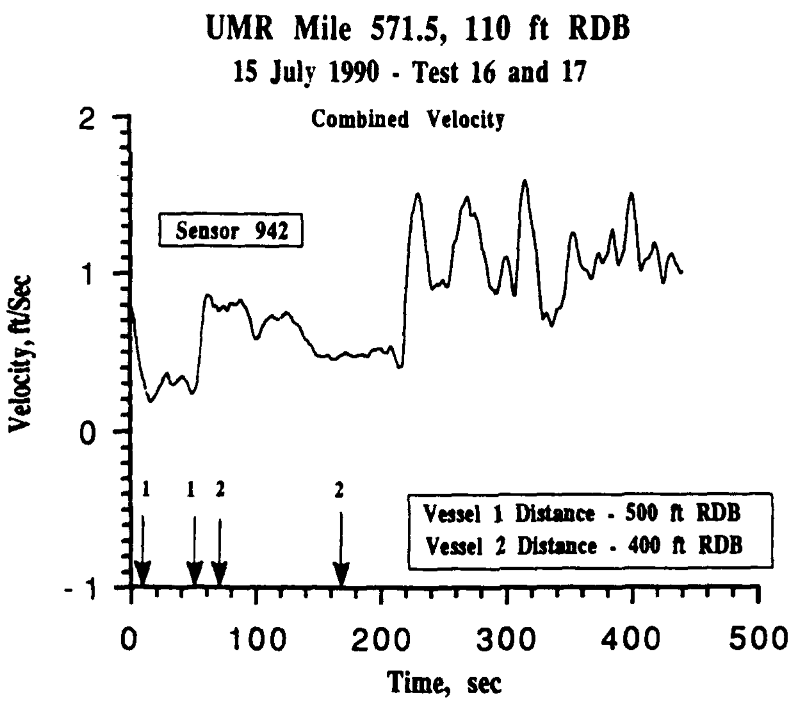
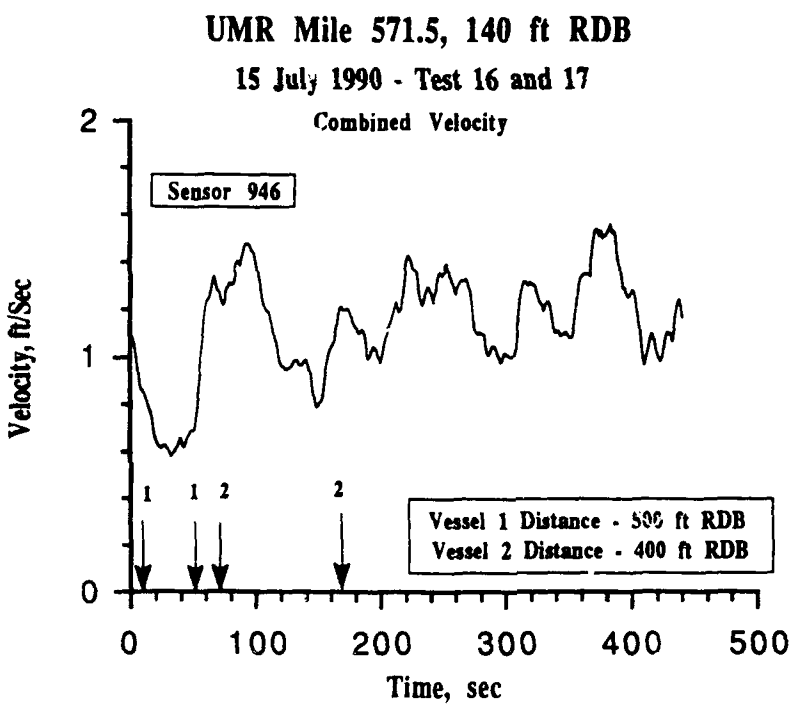


Figure E46

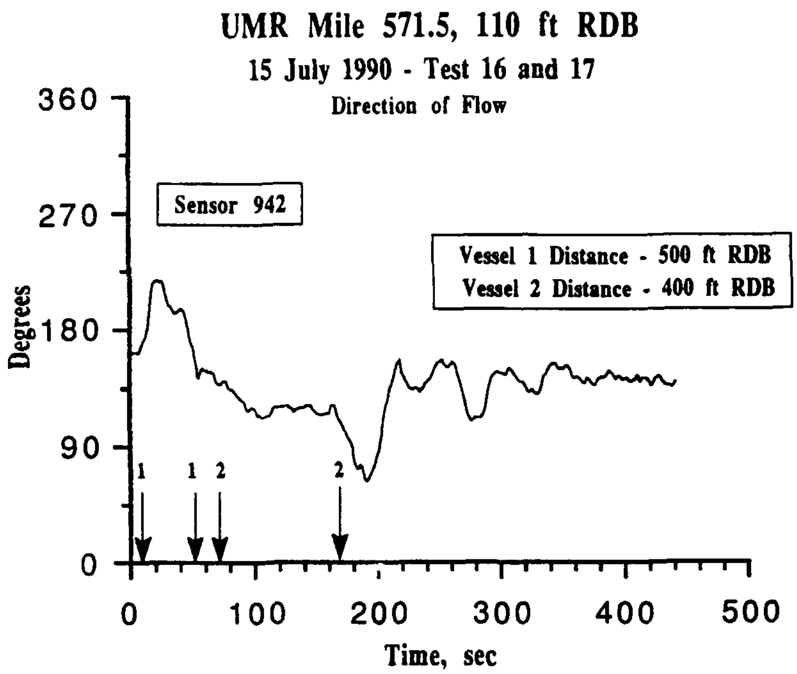


UMR Mile 571.5, 110 ft RDB
15 July 1990 - Test 16 and 17
Combined Velocity
Sensor 942
Vessel 1 Distance - 500 ft RDB
Vessel 2 Distance - 400 ft RDB
Velocity, ft/Sec
Time, sec
2
1
0
-1
0
100
200
300
400
500
1
1
2
2



UMR Mile 571.5, 140 ft RDB
15 July 1990 - Test 16 and 17
Combined Velocity
Sensor 946
Vessel 1 Distance - 500 ft RDB
Vessel 2 Distance - 400 ft RDB
Velocity, ft/Sec
Time, sec
2
1
0
0
100
200
300
400
500
1
1
2
2

Figure E47


UMR Mile 571.5, 110 ft RDB
15 July 1990 - Test 16 and 17
Direction of Flow
Sensor 942
Vessel 1 Distance - 500 ft RDB
Vessel 2 Distance - 400 ft RDB
Degrees
Time, sec
360
270
180
90
0
0
100
200
300
400
500
1
1
2
2

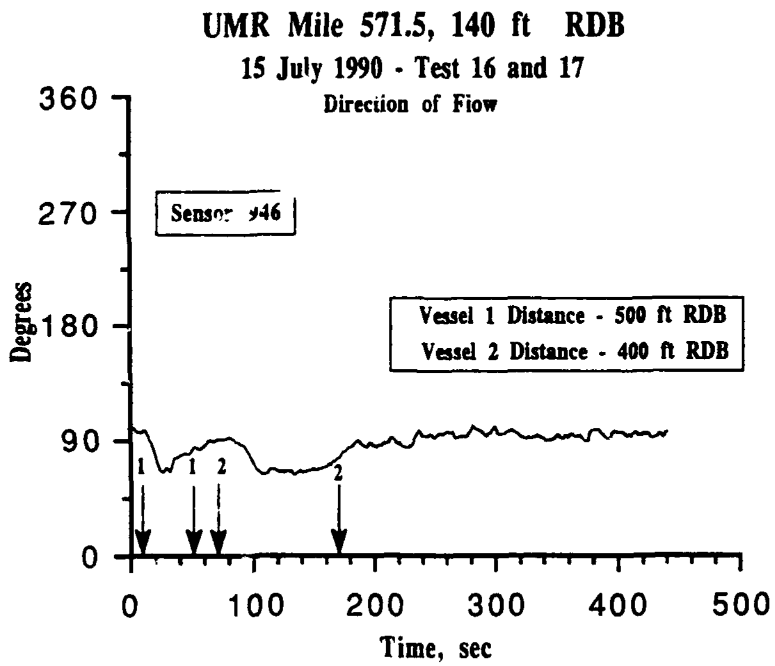

UMR Mile 571.5, 140 ft RDB
15 July 1990 - Test 16 and 17
Direction of Flow
Vessel 1 Distance - 500 ft RDB
Vessel 2 Distance - 400 ft RDB
Degrees
Time, sec
360
270
180
90
0
0
100
200
300
400
500
1
1
2
2

Figure E48

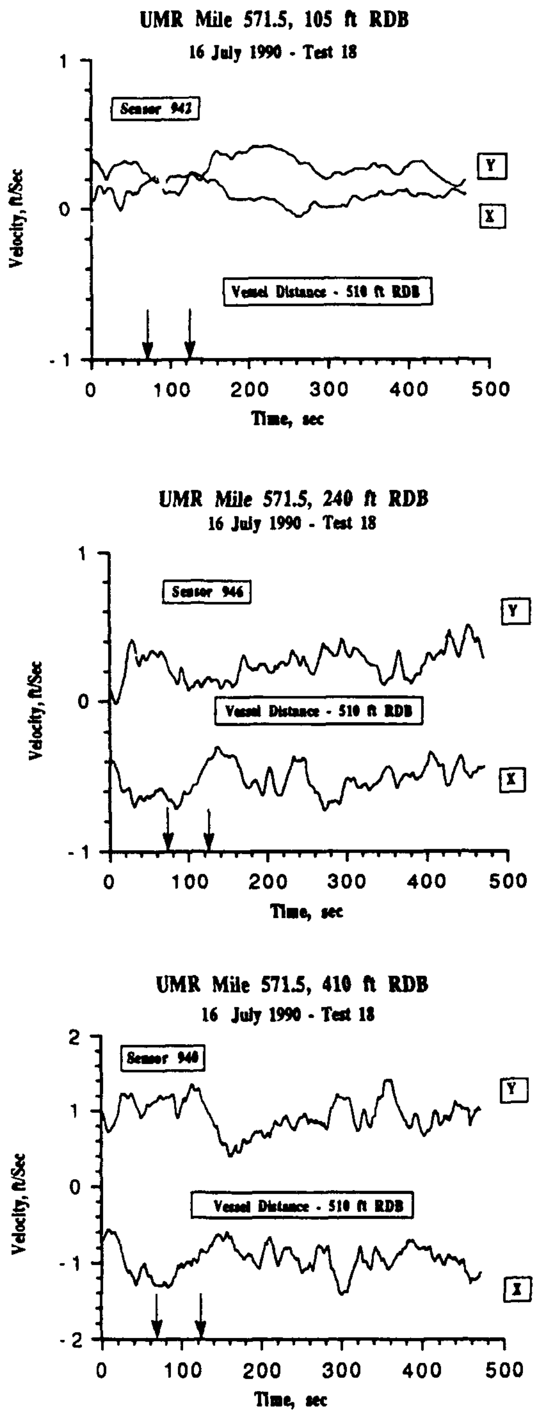
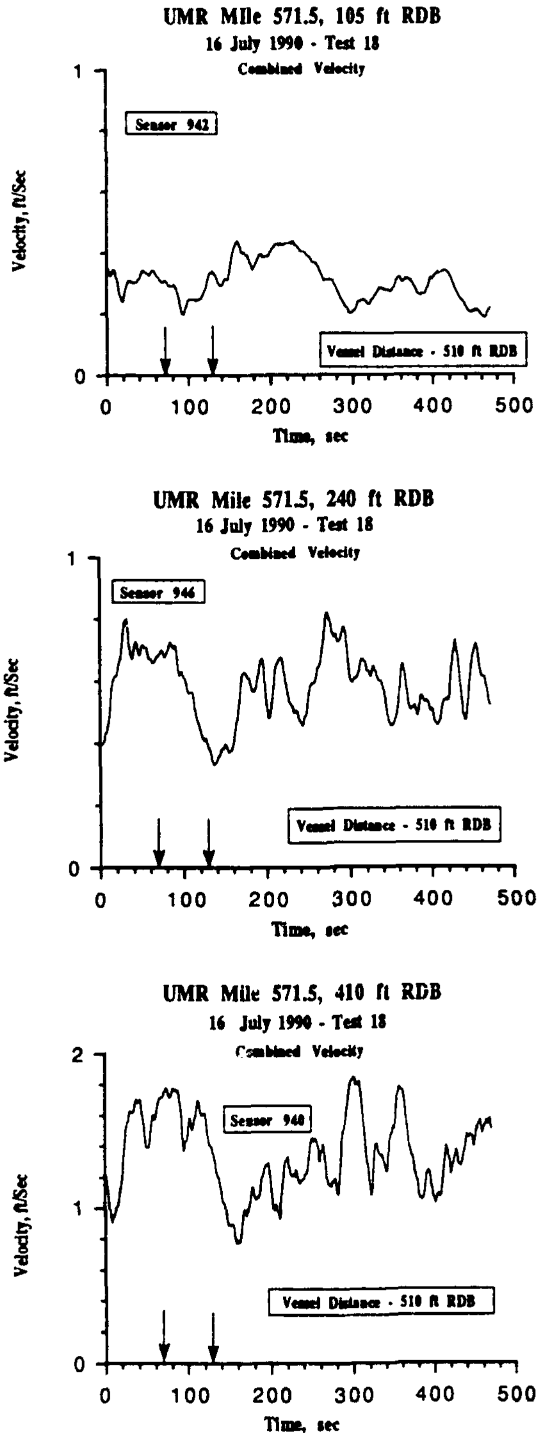
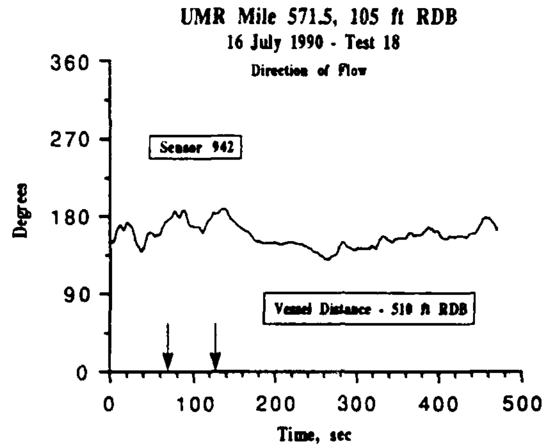

UMR Mile 571.5, 105 ft RDB
16 July 1990 - Test 18
Sensor 942
Y
X
Vessel Distance - 510 ft RDB
Velocity, ft/Sec
Time, sec
UMR Mile 571.5, 240 ft RDB
16 July 1990 - Test 18
Sensor 946
Y
X
Vessel Distance - 510 ft RDB
Velocity, ft/Sec
Time, sec
UMR Mile 571.5, 410 ft RDB
16 July 1990 - Test 18
Sensor 940
Y
X
Vessel Distance - 510 ft RDB
Velocity, ft/Sec
Time, sec

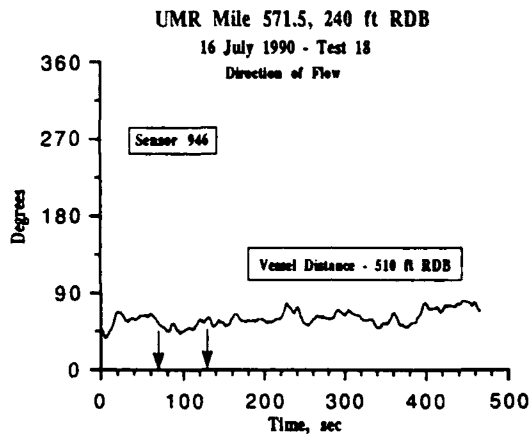
Figure E49



UMR MIle 571.5, 105 ft RDB
16 July 1990 - Test 18
Combined Velocity
Sensor 942
Velocity, ft/Sec
Vessel Distance - 510 ft RDB
0
1
0
100
200
300
400
500
Time, sec
UMR Mile 571.5, 240 ft RDB
16 July 1990 - Test 18
Combined Velocity
Sensor 946
Velocity, ft/Sec
Vessel Distance - 510 ft RDB
0
1
0
100
200
300
400
500
Time, sec
UMR Mile 571.5, 410 ft RDB
16 July 1990 - Test 18
Combined Velocity
Sensor 940
Velocity, ft/Sec
Vessel Distance - 510 ft RDB
0
1
2
0
100
200
300
400
500
Time, sec

Figure E50


UMR Mile 571.5, 105 ft RDB
16 July 1990 - Test 18
Direction of Flow
Sensor 942
Vessel Distance - 510 ft RDB
Degrees
Time, sec
0
90
180
270
360
0
100
200
300
400
500


UMR Mile 571.5, 240 ft RDB
16 July 1990 - Test 18
Direction of Flow
Sensor 946
Vessel Distance - 510 ft RDB
Degrees
Time, sec
0
90
180
270
360
0
100
200
300
400
500

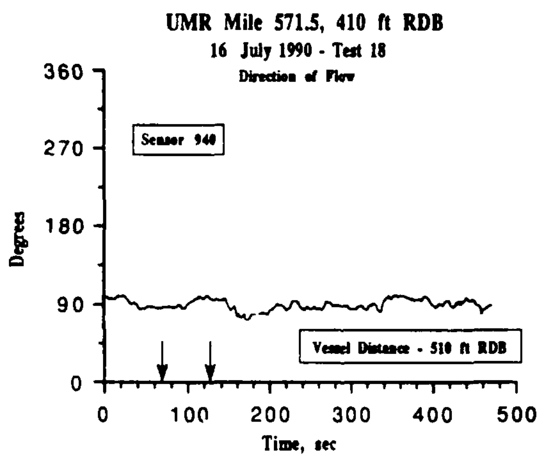
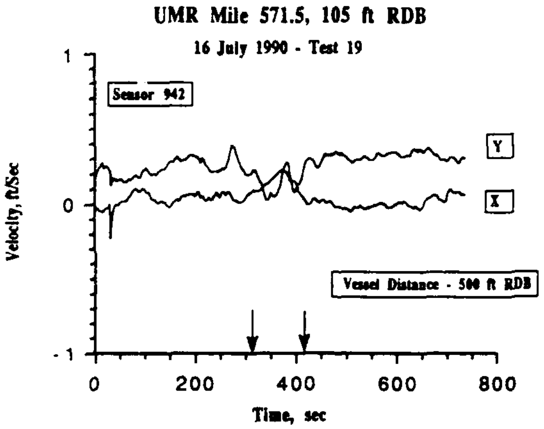
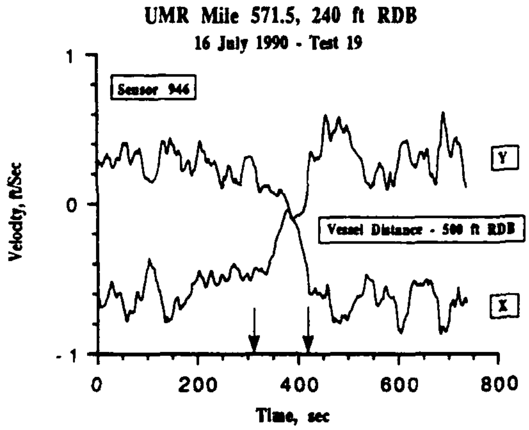

UMR Mile 571.5, 410 ft RDB
16 July 1990 - Test 18
Direction of Flow
Sensor 940
Vessel Distance - 510 ft RDB
Degrees
Time, sec
0
90
180
270
360
0
100
200
300
400
500

Figure E51


UMR Mile 571.5, 105 ft RDB
16 July 1990 - Test 19
Sensor 942
Y
X
Vessel Distance - 500 ft RDB
Velocity, ft/Sec
Time, sec


UMR Mile 571.5, 240 ft RDB
16 July 1990 - Test 19
Sensor 946
Y
X
Vessel Distance - 500 ft RDB
Velocity, ft/Sec
Time, sec

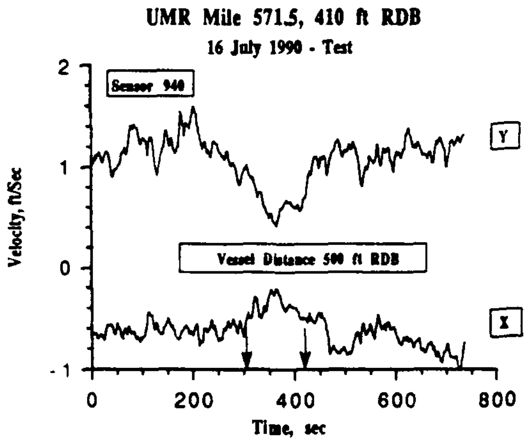
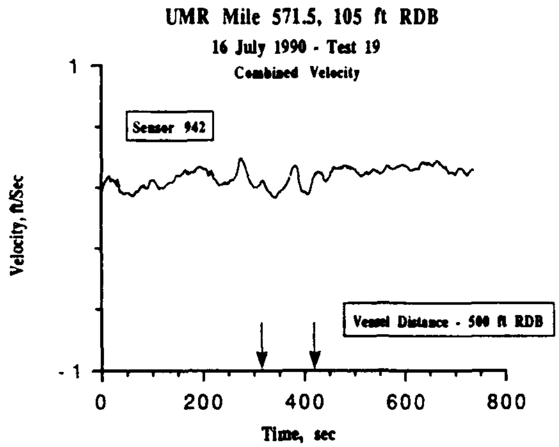
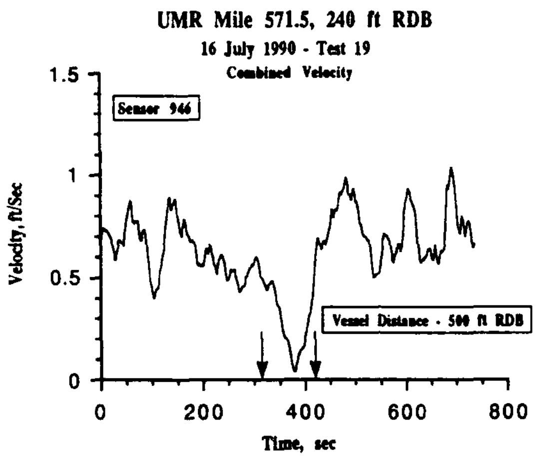

UMR Mile 571.5, 410 ft RDB
16 July 1990 - Test
Sensor 940
Y
X
Vessel Distance 500 ft RDB
Velocity, ft/Sec
Time, sec

Figure E52


UMR Mile 571.5, 105 ft RDB
16 July 1990 - Test 19
Combined Velocity
Sensor 942
Vessel Distance - 500 ft RDB
Velocity, ft/Sec
Time, sec
1
-1
0
200
400
600
800


UMR Mile 571.5, 240 ft RDB
16 July 1990 - Test 19
Combined Velocity
Sensor 946
Vessel Distance - 500 ft RDB
Velocity, ft/Sec
Time, sec
1.5
1
0.5
0
0
200
400
600
800

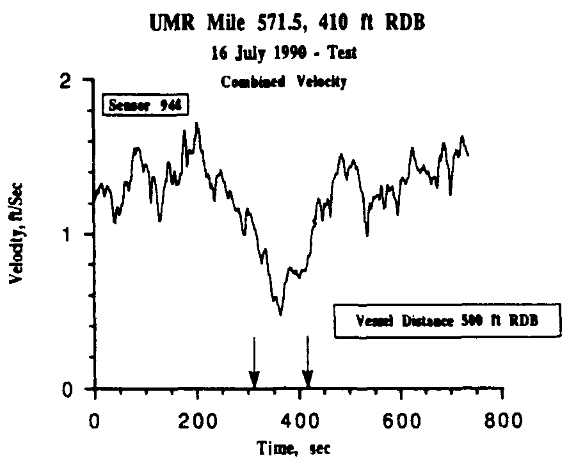

UMR Mile 571.5, 410 ft RDB
16 July 1990 - Test
Combined Velocity
Sensor 944
Vessel Distance 500 ft RDB
Velocity, ft/Sec
Time, sec
2
1
0
0
200
400
600
800

Figure E53

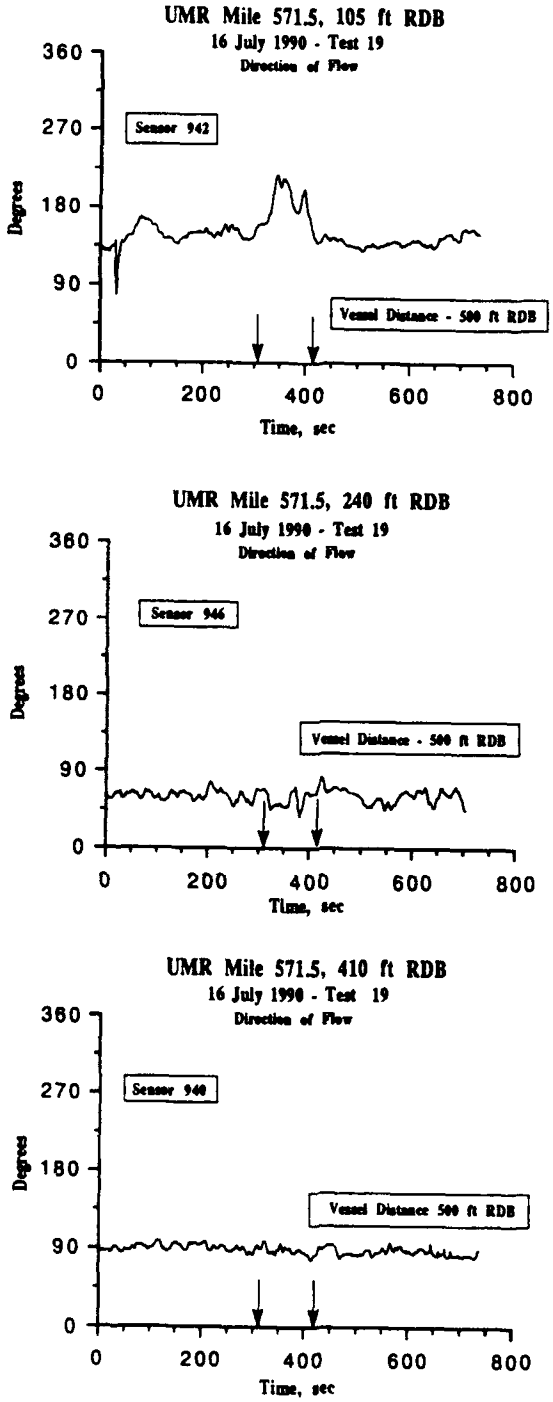
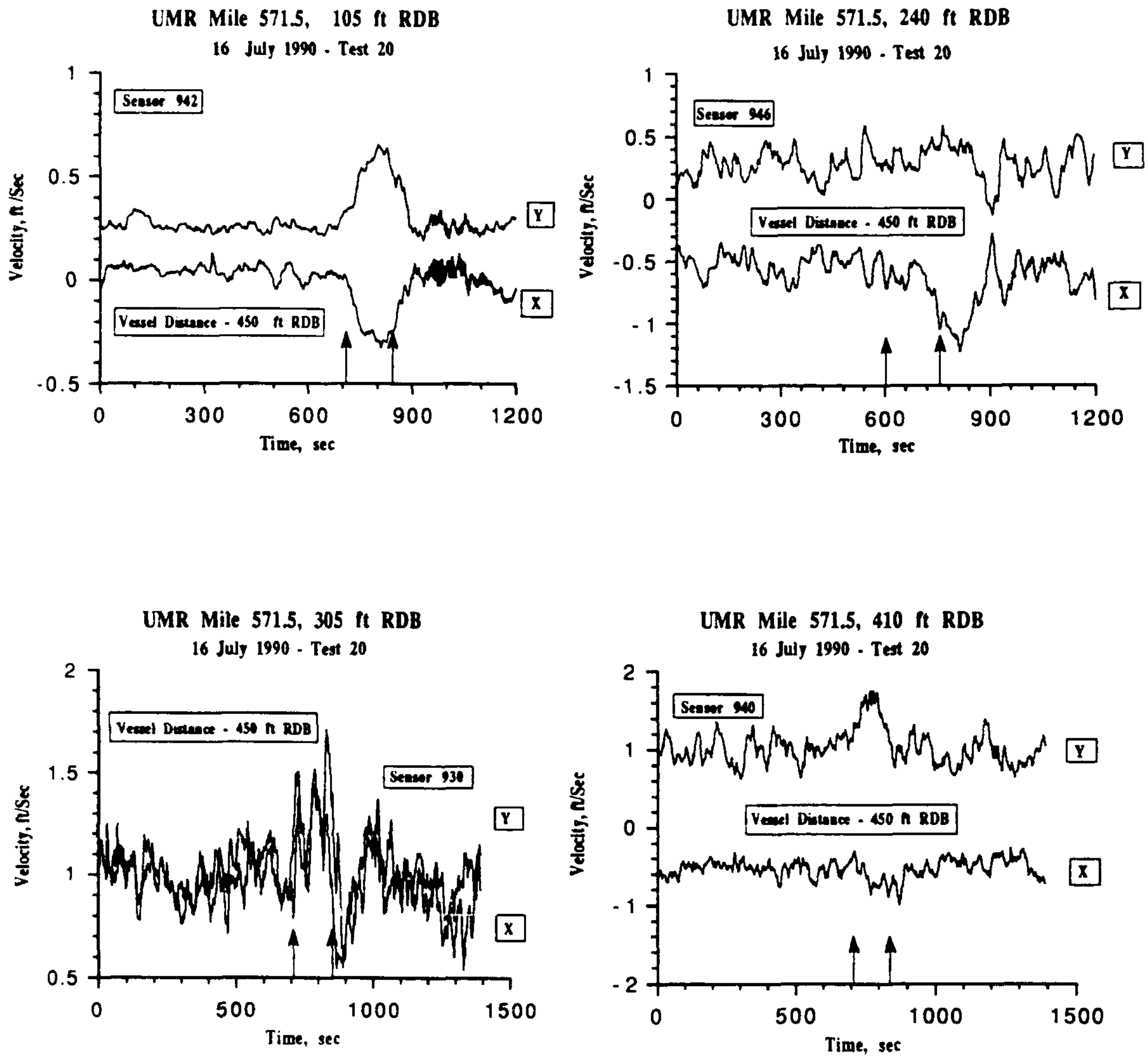

UMR Mile 571.5, 105 ft RDB
16 July 1990 - Test 19
Direction of Flow
Sensor 942
Vessel Distance - 500 ft RDB
Degrees
Time, sec
360
270
180
90
0
0
200
400
600
800
UMR Mile 571.5, 240 ft RDB
16 July 1990 - Test 19
Direction of Flow
Sensor 946
Vessel Distance - 500 ft RDB
Degrees
Time, sec
UMR Mile 571.5, 410 ft RDB
16 July 1990 - Test 19
Direction of Flow
Sensor 940
Vessel Distance 500 ft RDB
Degrees
Time, sec

Figure E54



UMR Mile 571.5, 105 ft RDB
16 July 1990 - Test 20
Sensor 942
Vessel Distance - 450 ft RDB
Velocity, ft/Sec
Time, sec
Y
X
UMR Mile 571.5, 240 ft RDB
16 July 1990 - Test 20
Sensor 946
Vessel Distance - 450 ft RDB
Velocity, ft/Sec
Time, sec
Y
X
UMR Mile 571.5, 305 ft RDB
16 July 1990 - Test 20
Vessel Distance - 450 ft RDB
Sensor 930
Velocity, ft/Sec
Time, sec
Y
X
UMR Mile 571.5, 410 ft RDB
16 July 1990 - Test 20
Sensor 940
Vessel Distance - 450 ft RDB
Velocity, ft/Sec
Time, sec
Y
X

Figure E55

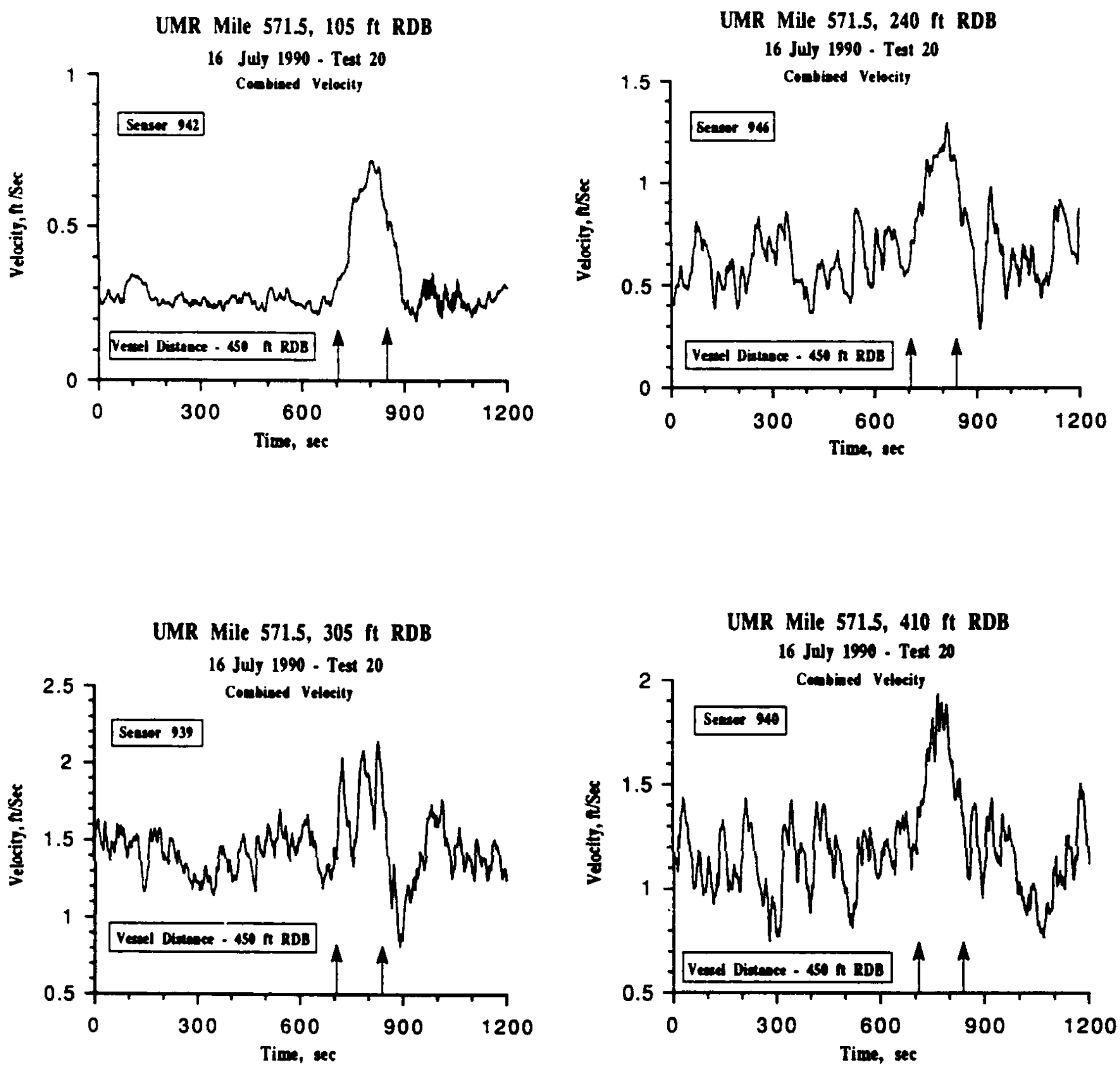

UMR Mile 571.5, 105 ft RDB
16 July 1990 - Test 20
Combined Velocity
Sensor 942
Vessel Distance - 450 ft RDB
Velocity, ft/Sec
Time, sec
UMR Mile 571.5, 240 ft RDB
16 July 1990 - Test 20
Combined Velocity
Sensor 946
Vessel Distance - 450 ft RDB
Velocity, ft/Sec
Time, sec
UMR Mile 571.5, 305 ft RDB
16 July 1990 - Test 20
Combined Velocity
Sensor 939
Vessel Distance - 450 ft RDB
Velocity, ft/Sec
Time, sec
UMR Mile 571.5, 410 ft RDB
16 July 1990 - Test 20
Combined Velocity
Sensor 940
Vessel Distance - 450 ft RDB
Velocity, ft/Sec
Time, sec

Figure E56

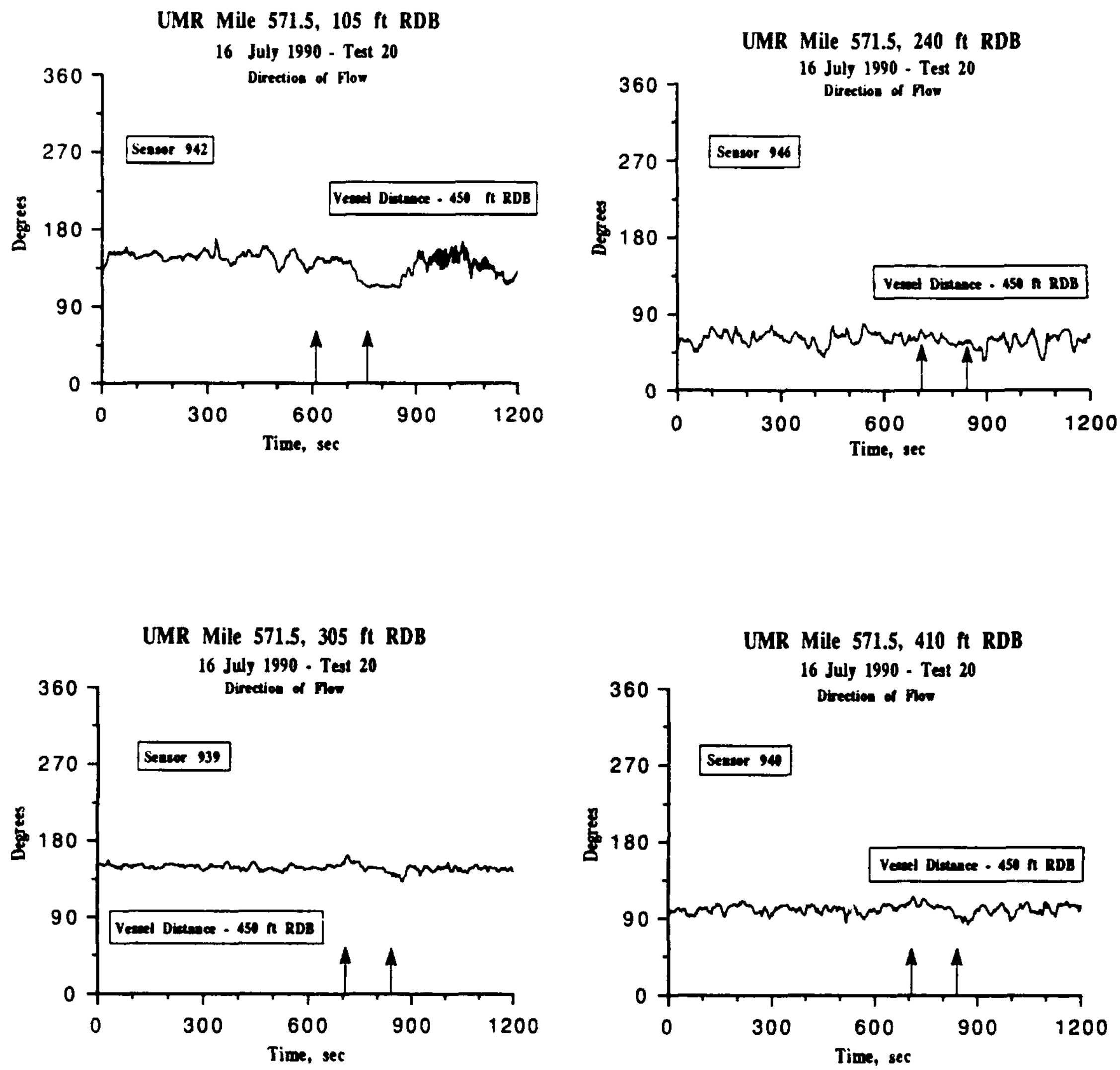

UMR Mile 571.5, 105 ft RDB
16 July 1990 - Test 20
Direction of Flow
Sensor 942
Vessel Distance - 450 ft RDB
Degrees
360
270
180
90
0
0
300
600
900
1200
Time, sec
UMR Mile 571.5, 240 ft RDB
16 July 1990 - Test 20
Direction of Flow
Sensor 946
Vessel Distance - 450 ft RDB
Degrees
360
270
180
90
0
0
300
600
900
1200
Time, sec
UMR Mile 571.5, 305 ft RDB
16 July 1990 - Test 20
Direction of Flow
Sensor 939
Vessel Distance - 450 ft RDB
Degrees
360
270
180
90
0
0
300
600
900
1200
Time, sec
UMR Mile 571.5, 410 ft RDB
16 July 1990 - Test 20
Direction of Flow
Sensor 940
Vessel Distance - 450 ft RDB
Degrees
360
270
180
90
0
0
300
600
900
1200
Time, sec

Figure E57

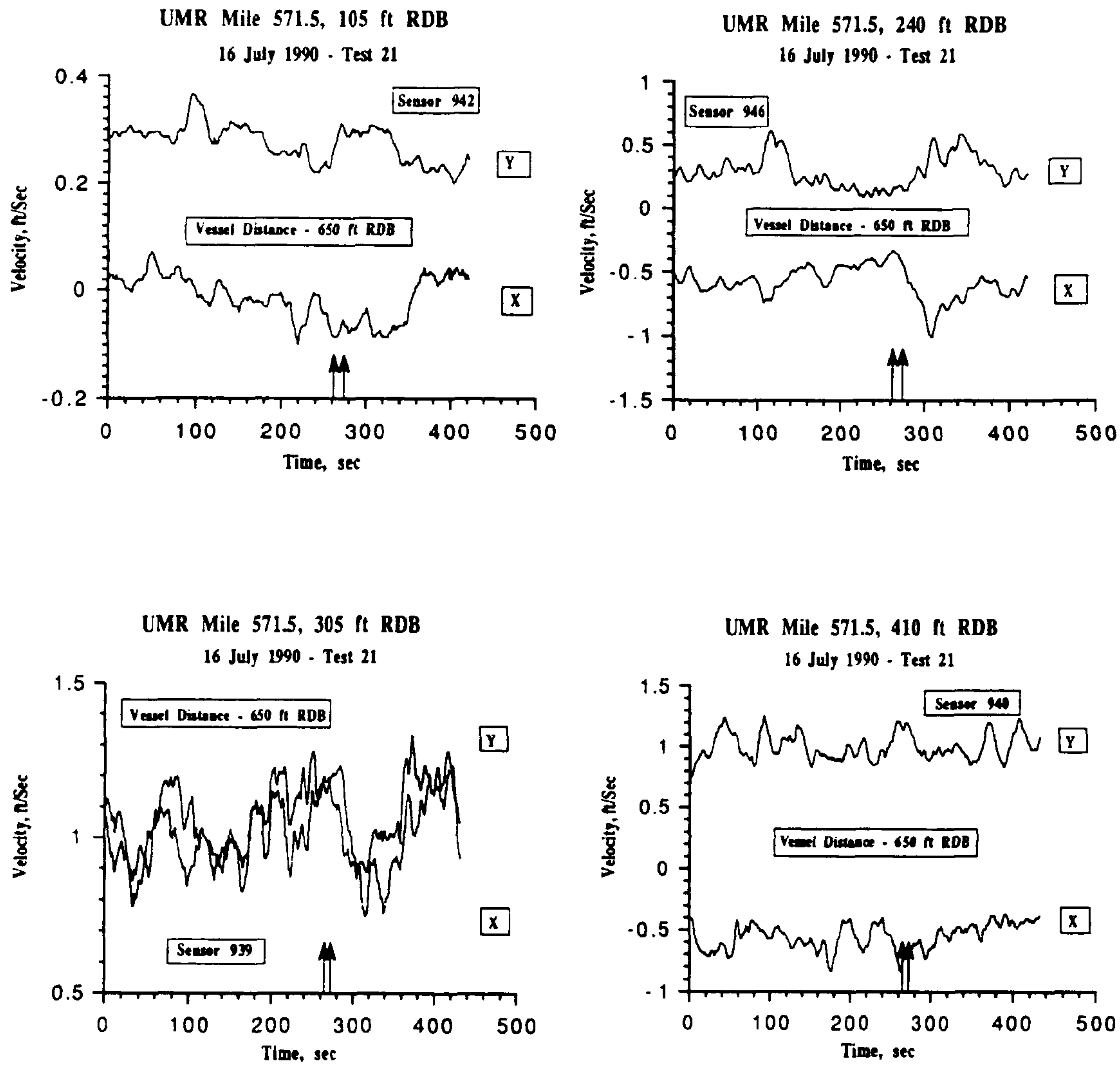

UMR Mile 571.5, 105 ft RDB
16 July 1990 - Test 21
Sensor 942
Vessel Distance - 650 ft RDB
Y
X
Velocity, ft/Sec
Time, sec
UMR Mile 571.5, 240 ft RDB
16 July 1990 - Test 21
Sensor 946
Vessel Distance - 650 ft RDB
Y
X
Velocity, ft/Sec
Time, sec
UMR Mile 571.5, 305 ft RDB
16 July 1990 - Test 21
Vessel Distance - 650 ft RDB
Sensor 939
Y
X
Velocity, ft/Sec
Time, sec
UMR Mile 571.5, 410 ft RDB
16 July 1990 - Test 21
Sensor 940
Vessel Distance - 650 ft RDB
Y
X
Velocity, ft/Sec
Time, sec

Figure E58

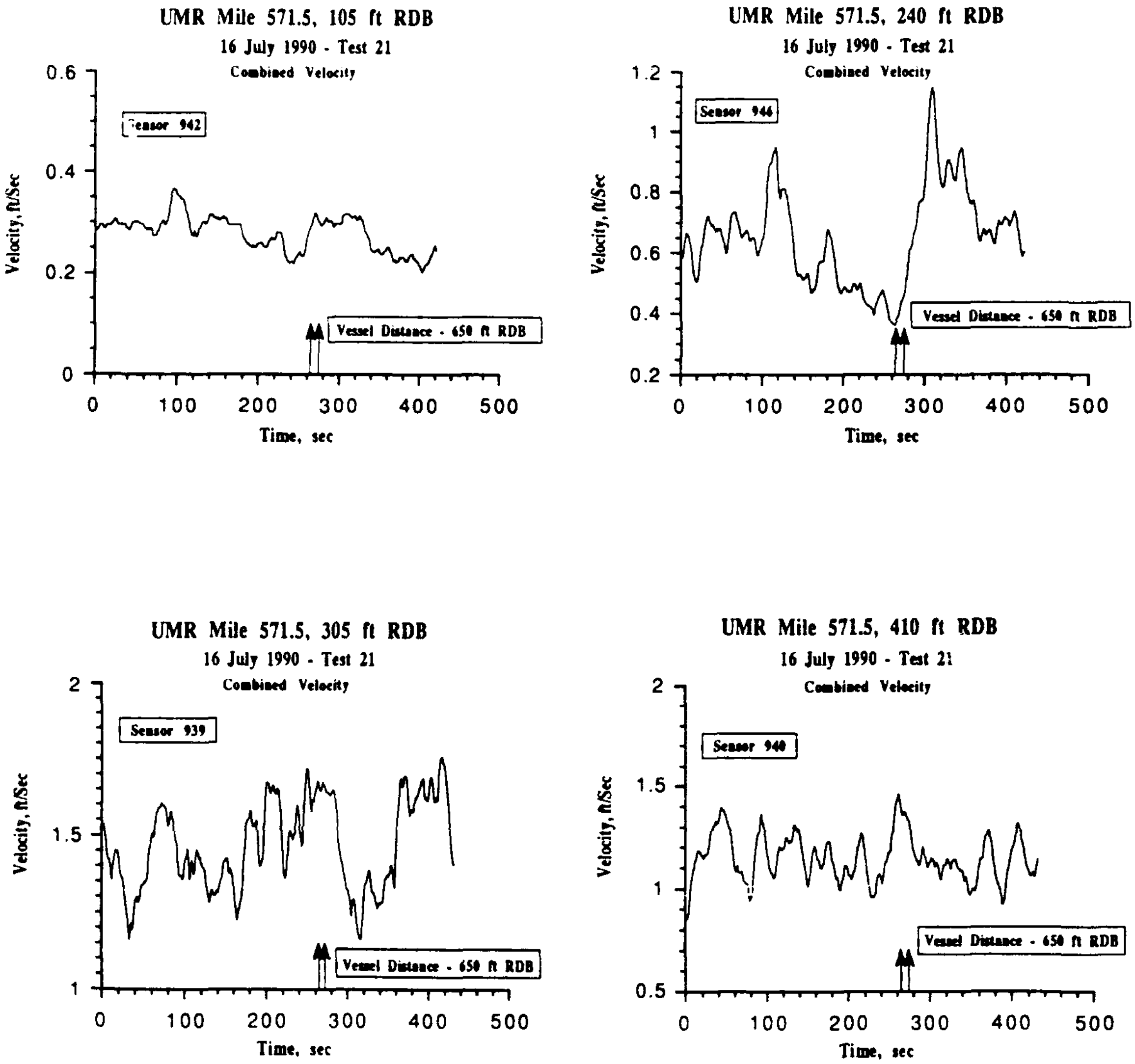

UMR Mile 571.5, 105 ft RDB
16 July 1990 - Test 21
Combined Velocity
Sensor 942
Vessel Distance - 650 ft RDB
Velocity, ft/Sec
Time, sec
UMR Mile 571.5, 240 ft RDB
16 July 1990 - Test 21
Combined Velocity
Sensor 946
Vessel Distance - 650 ft RDB
Velocity, ft/Sec
Time, sec
UMR Mile 571.5, 305 ft RDB
16 July 1990 - Test 21
Combined Velocity
Sensor 939
Vessel Distance - 650 ft RDB
Velocity, ft/Sec
Time, sec
UMR Mile 571.5, 410 ft RDB
16 July 1990 - Test 21
Combined Velocity
Sensor 940
Vessel Distance - 650 ft RDB
Velocity, ft/Sec
Time, sec

Figure E59

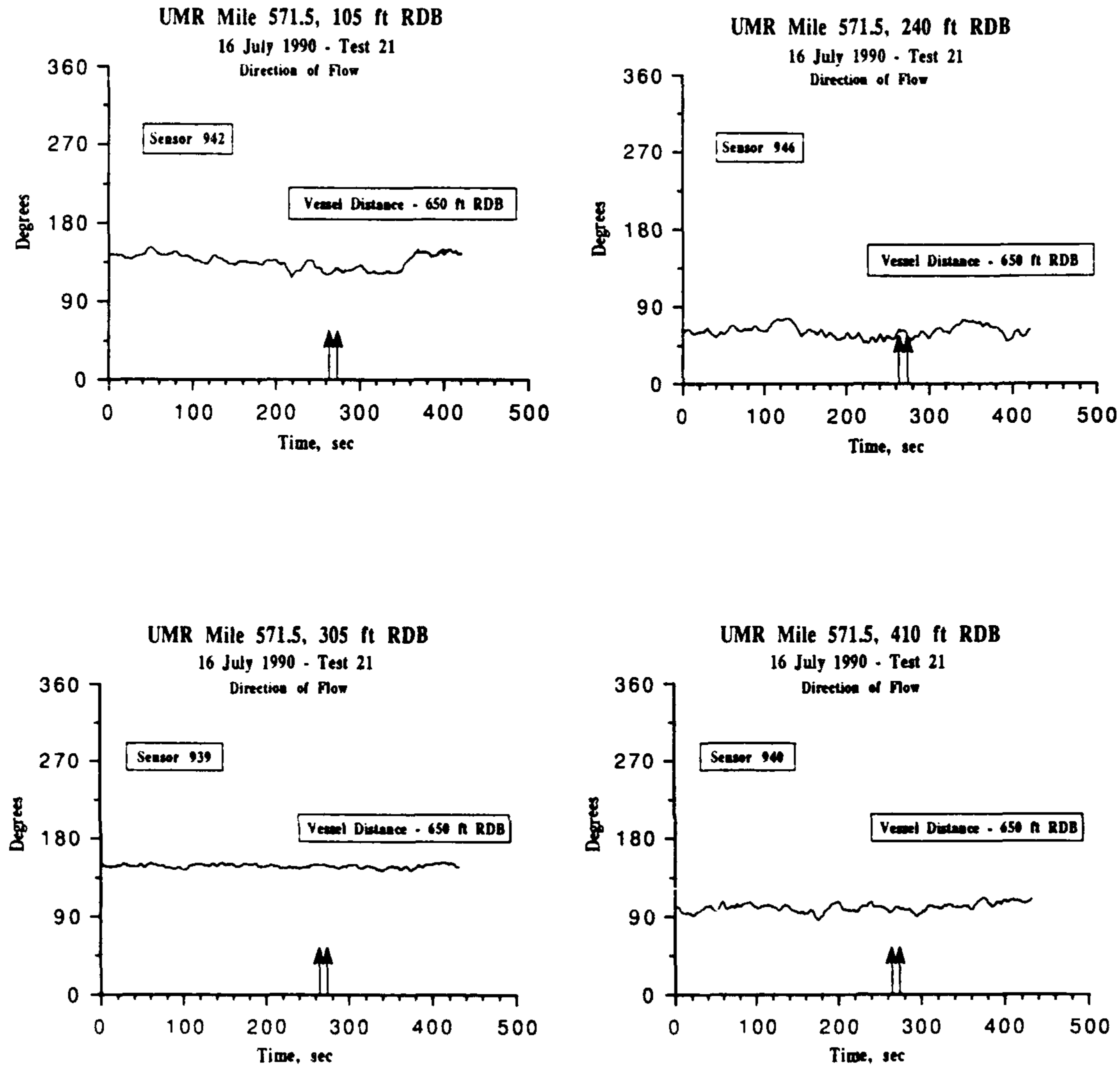
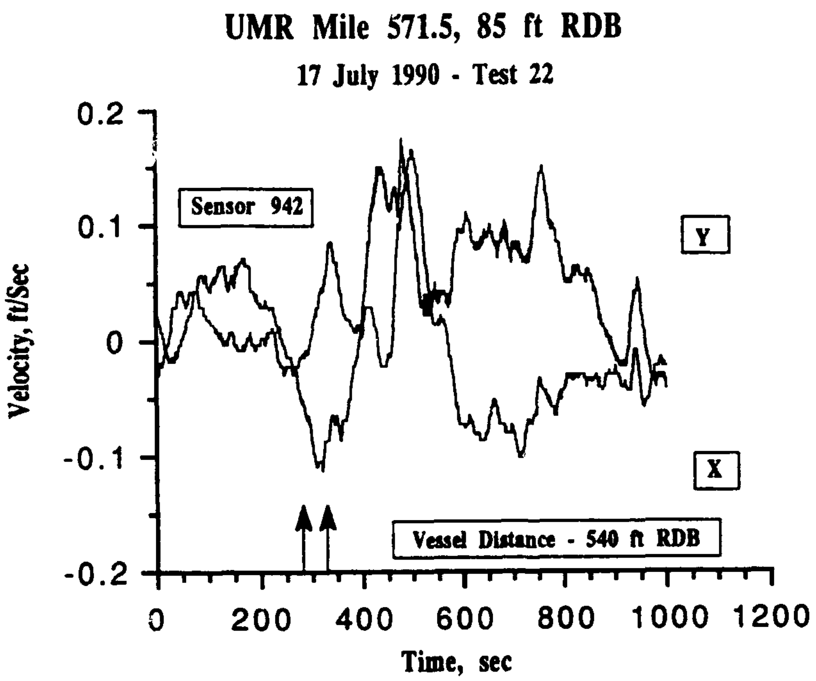

UMR Mile 571.5, 105 ft RDB
16 July 1990 - Test 21
Direction of Flow
Sensor 942
Vessel Distance - 650 ft RDB
Degrees
Time, sec
UMR Mile 571.5, 240 ft RDB
16 July 1990 - Test 21
Direction of Flow
Sensor 946
Vessel Distance - 650 ft RDB
UMR Mile 571.5, 305 ft RDB
16 July 1990 - Test 21
Direction of Flow
Sensor 939
Vessel Distance - 650 ft RDB
UMR Mile 571.5, 410 ft RDB
16 July 1990 - Test 21
Direction of Flow
Sensor 940
Vessel Distance - 650 ft RDB

Figure E60


UMR Mile 571.5, 85 ft RDB
17 July 1990 - Test 22
Sensor 942
Y
X
Vessel Distance - 540 ft RDB
Velocity, ft/Sec
Time, sec
0.2
0.1
0
-0.1
-0.2
0
200
400
600
800
1000
1200

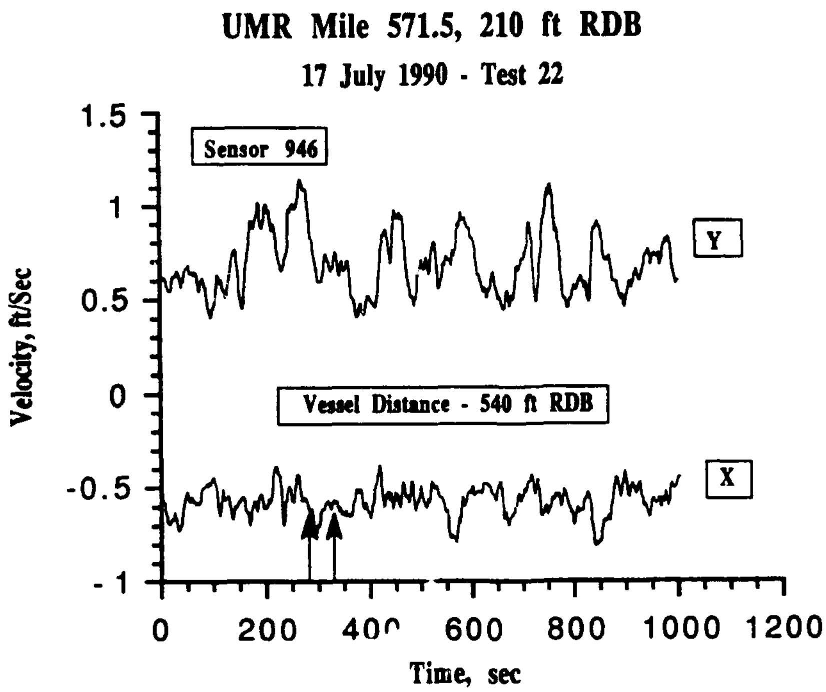
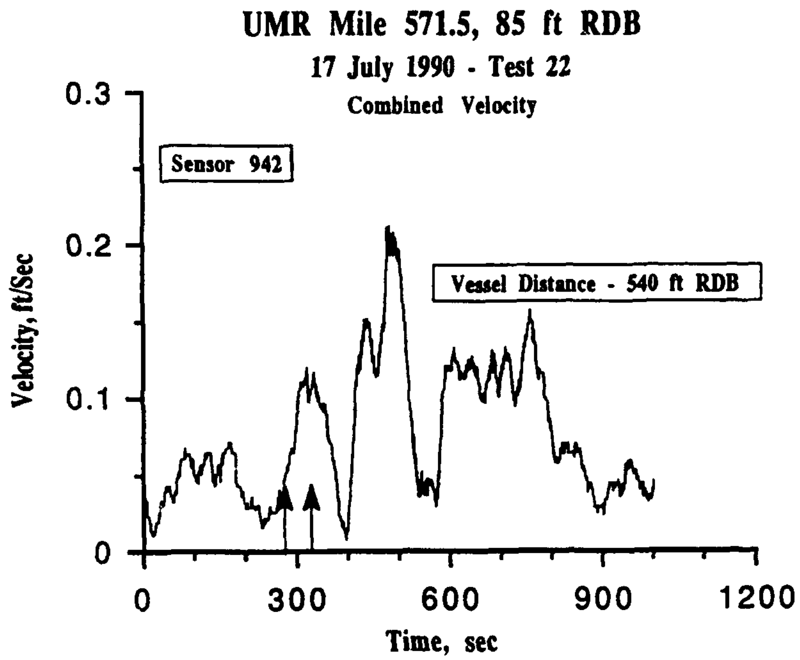

UMR Mile 571.5, 210 ft RDB
17 July 1990 - Test 22
Sensor 946
Y
Vessel Distance - 540 ft RDB
X
Velocity, ft/Sec
Time, sec
1.5
1
0.5
0
-0.5
- 1
0
200
600
800
1000
1200

Figure E61


UMR Mile 571.5, 85 ft RDB
17 July 1990 - Test 22
Combined Velocity
Sensor 942
Vessel Distance - 540 ft RDB
Velocity, ft/Sec
0.3
0.2
0.1
0
0
300
600
900
1200
Time, sec

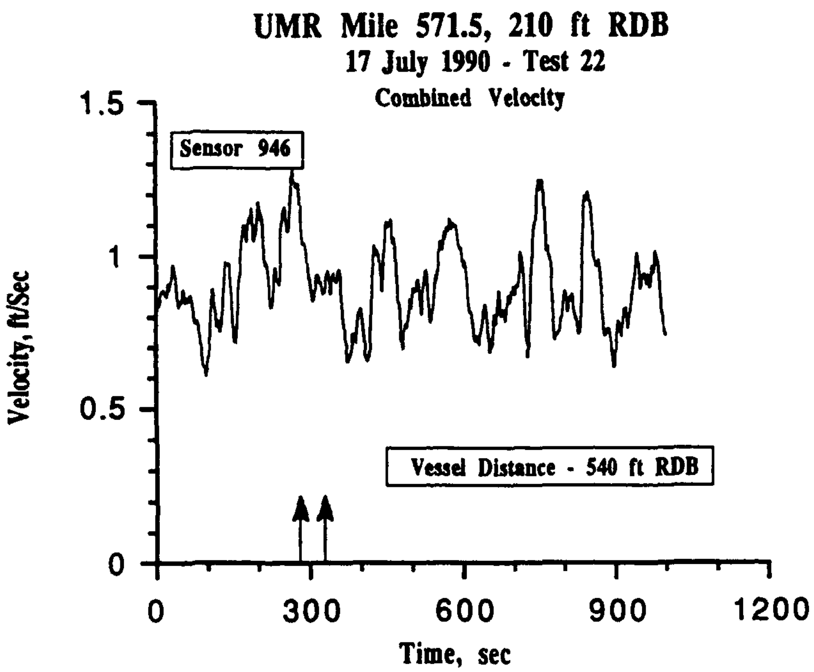
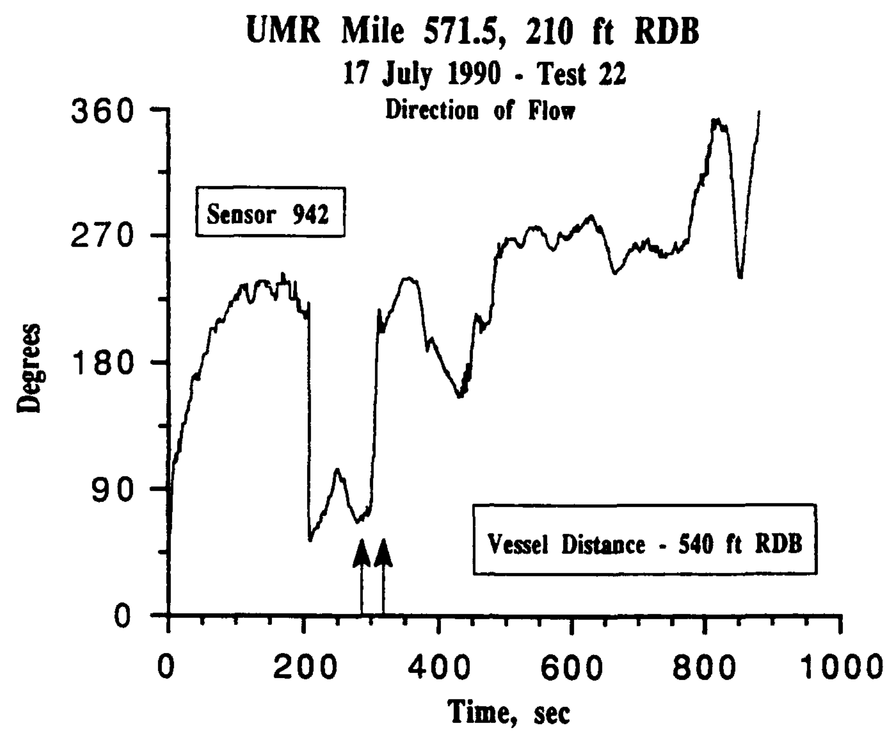

UMR Mile 571.5, 210 ft RDB
17 July 1990 - Test 22
Combined Velocity
Sensor 946
Vessel Distance - 540 ft RDB
Velocity, ft/Sec
1.5
1
0.5
0
0
300
600
900
1200
Time, sec

Figure E62


UMR Mile 571.5, 210 ft RDB
17 July 1990 - Test 22
Direction of Flow
Sensor 942
Vessel Distance - 540 ft RDB
Degrees
360
270
180
90
0
0
200
400
600
800
1000
Time, sec

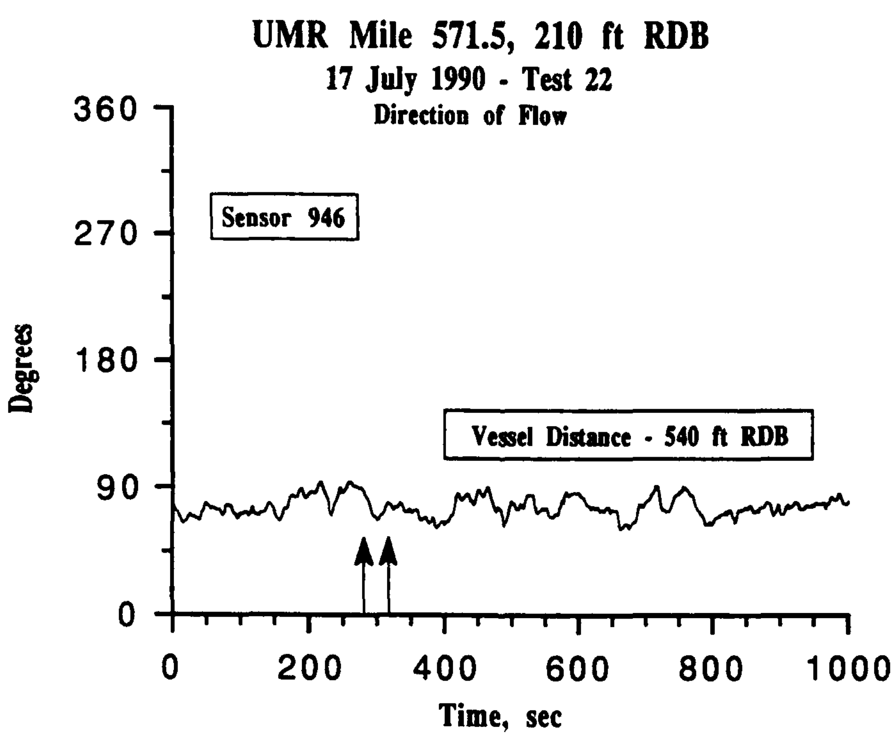
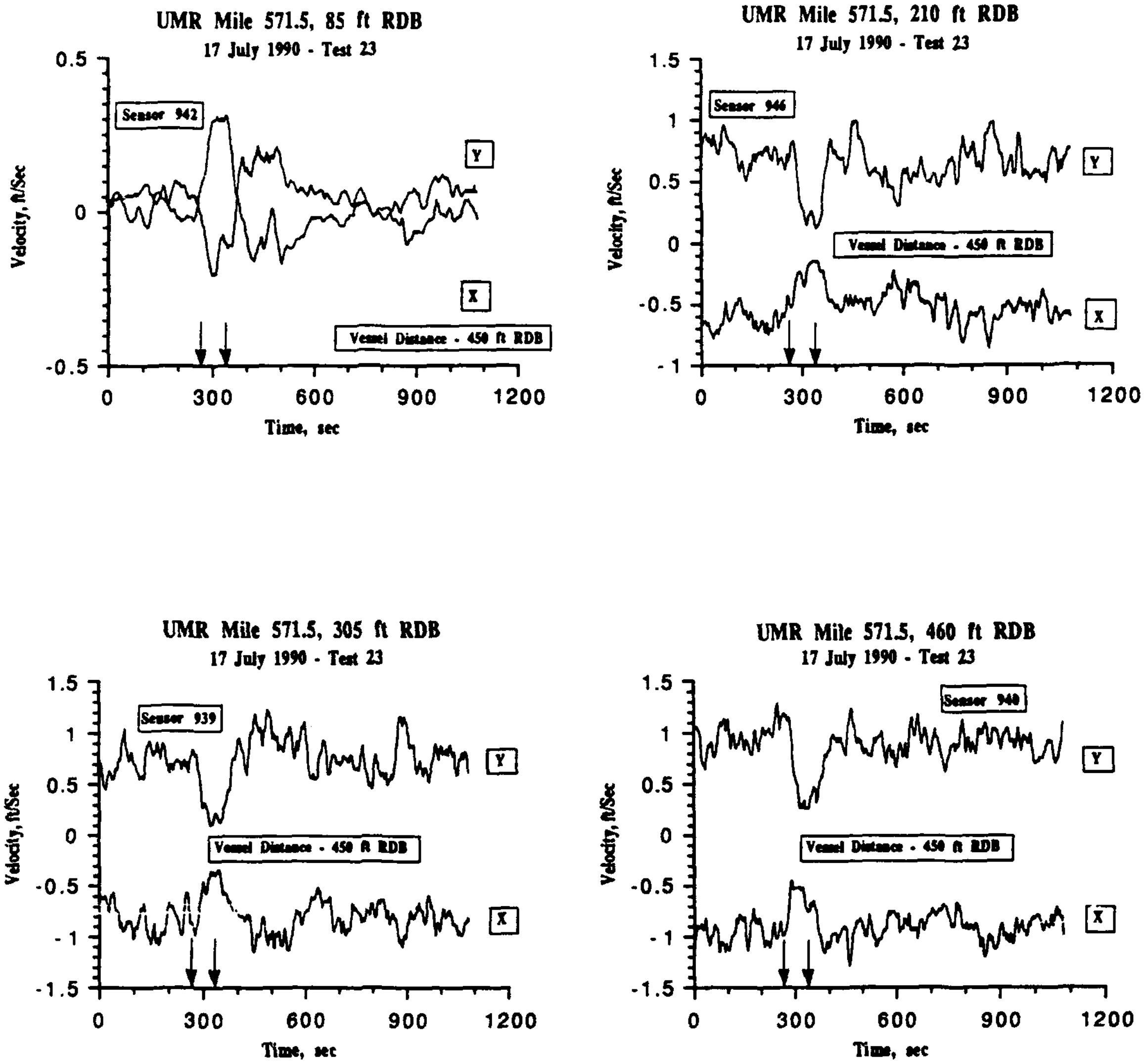

UMR Mile 571.5, 210 ft RDB
17 July 1990 - Test 22
Direction of Flow
Sensor 946
Vessel Distance - 540 ft RDB
Degrees
360
270
180
90
0
0
200
400
600
800
1000
Time, sec

Figure E63



UMR Mile 571.5, 85 ft RDB
17 July 1990 - Test 23
Sensor 942
Y
X
Vessel Distance - 450 ft RDB
Velocity, ft/Sec
Time, sec
UMR Mile 571.5, 210 ft RDB
17 July 1990 - Test 23
Sensor 946
Y
X
Vessel Distance - 450 ft RDB
Velocity, ft/Sec
Time, sec
UMR Mile 571.5, 305 ft RDB
17 July 1990 - Test 23
Sensor 939
Y
X
Vessel Distance - 450 ft RDB
Velocity, ft/Sec
Time, sec
UMR Mile 571.5, 460 ft RDB
17 July 1990 - Test 23
Sensor 940
Y
X
Vessel Distance - 450 ft RDB
Velocity, ft/Sec
Time, sec

Figure E64

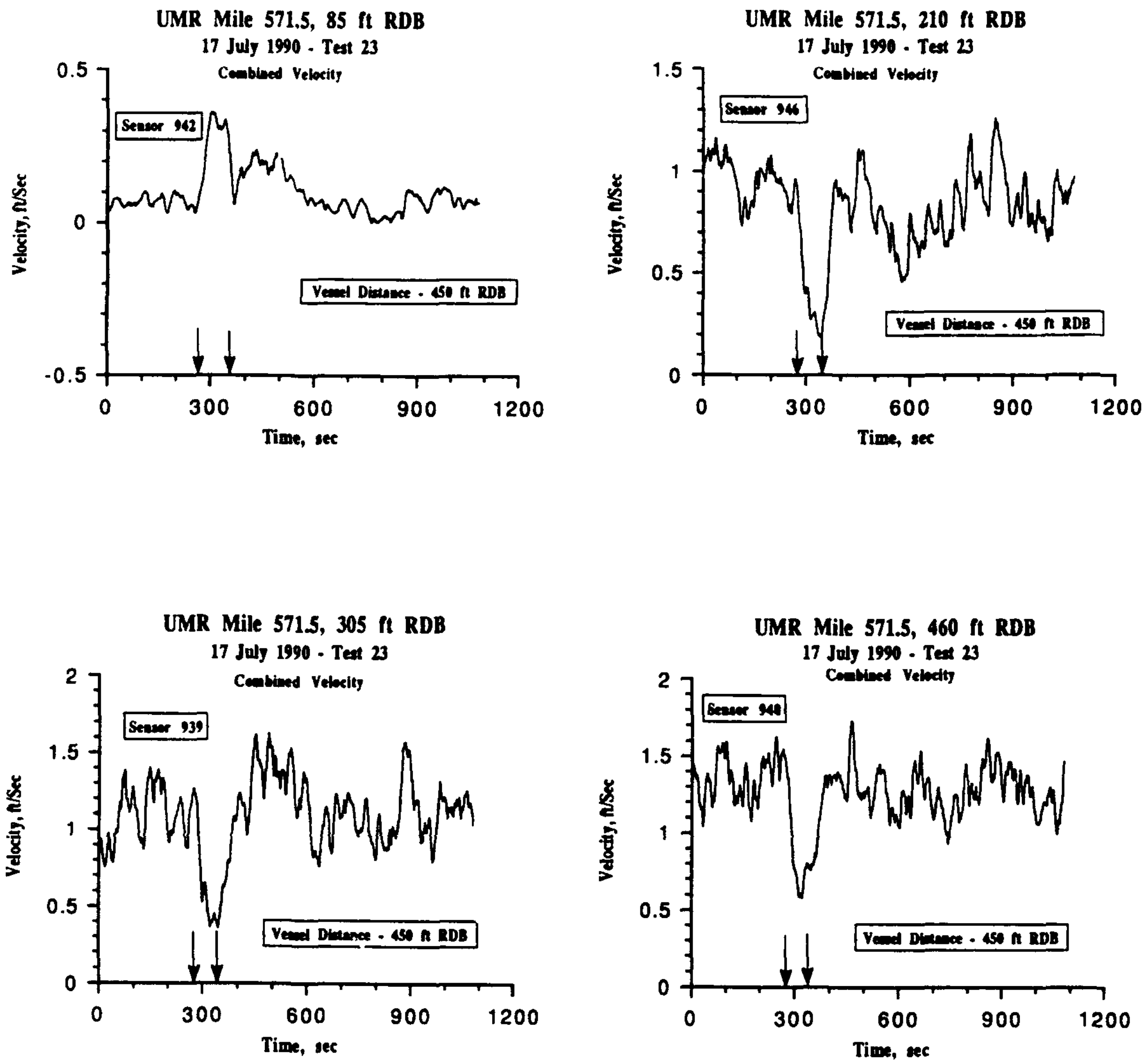

UMR Mile 571.5, 85 ft RDB
17 July 1990 - Test 23
Combined Velocity
Sensor 942
Vessel Distance - 450 ft RDB
Velocity, ft/Sec
Time, sec
0.5
0
-0.5
0
300
600
900
1200
UMR Mile 571.5, 210 ft RDB
17 July 1990 - Test 23
Combined Velocity
Sensor 946
Vessel Distance - 450 ft RDB
Velocity, ft/Sec
Time, sec
1.5
1
0.5
0
0
300
600
900
1200
UMR Mile 571.5, 305 ft RDB
17 July 1990 - Test 23
Combined Velocity
Sensor 939
Vessel Distance - 450 ft RDB
Velocity, ft/Sec
Time, sec
2
1.5
1
0.5
0
0
300
600
900
1200
UMR Mile 571.5, 460 ft RDB
17 July 1990 - Test 23
Combined Velocity
Sensor 948
Vessel Distance - 450 ft RDB
Velocity, ft/Sec
Time, sec
2
1.5
1
0.5
0
0
300
600
900
1200

Figure E65

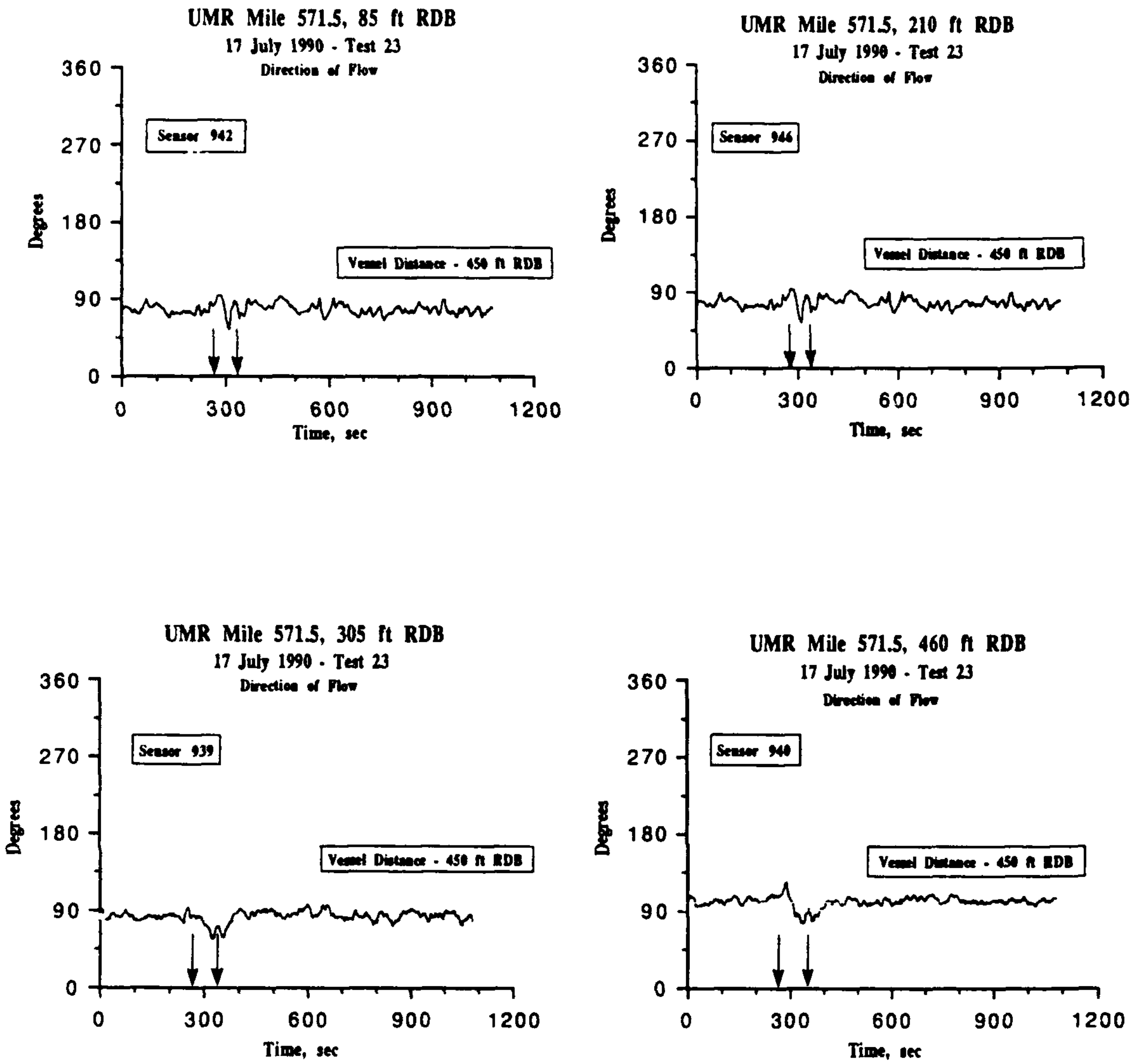

UMR Mile 571.5, 85 ft RDB
17 July 1990 - Test 23
Direction of Flow
Sensor 942
Vessel Distance - 450 ft RDB
Degrees
Time, sec
UMR Mile 571.5, 210 ft RDB
17 July 1990 - Test 23
Direction of Flow
Sensor 946
Vessel Distance - 450 ft RDB
Degrees
Time, sec
UMR Mile 571.5, 305 ft RDB
17 July 1990 - Test 23
Direction of Flow
Sensor 939
Vessel Distance - 450 ft RDB
Degrees
Time, sec
UMR Mile 571.5, 460 ft RDB
17 July 1990 - Test 23
Direction of Flow
Sensor 940
Vessel Distance - 450 ft RDB
Degrees
Time, sec

Figure E66

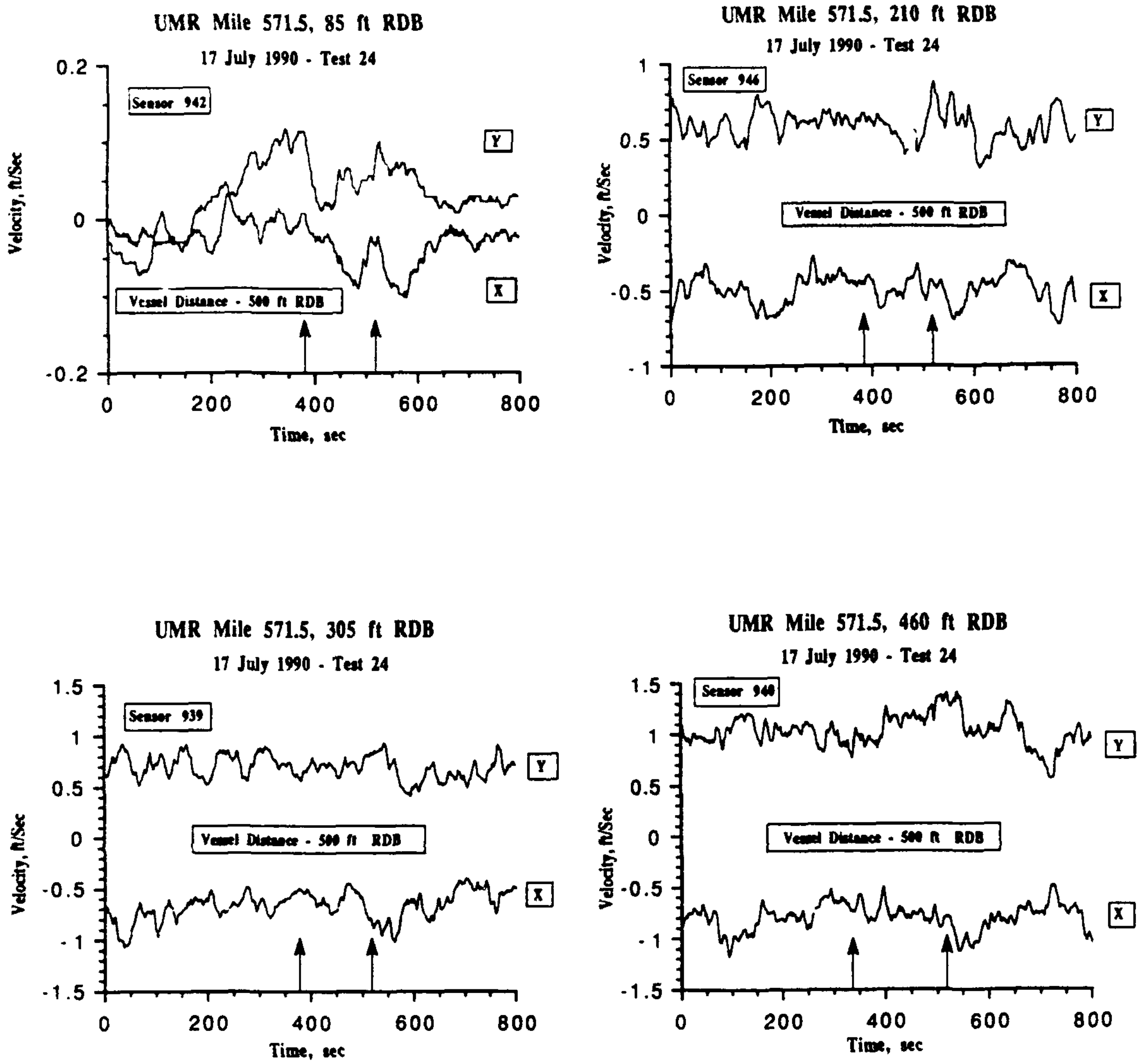

UMR Mile 571.5, 85 ft RDB
17 July 1990 - Test 24
Sensor 942
Y
X
Vessel Distance - 500 ft RDB
Velocity, ft/Sec
0.2
0
-0.2
0
200
400
600
800
Time, sec
UMR Mile 571.5, 210 ft RDB
17 July 1990 - Test 24
Sensor 946
Y
X
Vessel Distance - 500 ft RDB
Velocity, ft/Sec
1
0.5
0
-0.5
-1
0
200
400
600
800
Time, sec
UMR Mile 571.5, 305 ft RDB
17 July 1990 - Test 24
Sensor 939
Y
X
Vessel Distance - 500 ft RDB
Velocity, ft/Sec
1.5
1
0.5
0
-0.5
-1
-1.5
0
200
400
600
800
Time, sec
UMR Mile 571.5, 460 ft RDB
17 July 1990 - Test 24
Sensor 940
Y
X
Vessel Distance - 500 ft RDB
Velocity, ft/Sec
1.5
1
0.5
0
-0.5
-1
-1.5
0
200
400
600
800
Time, sec

Figure E67

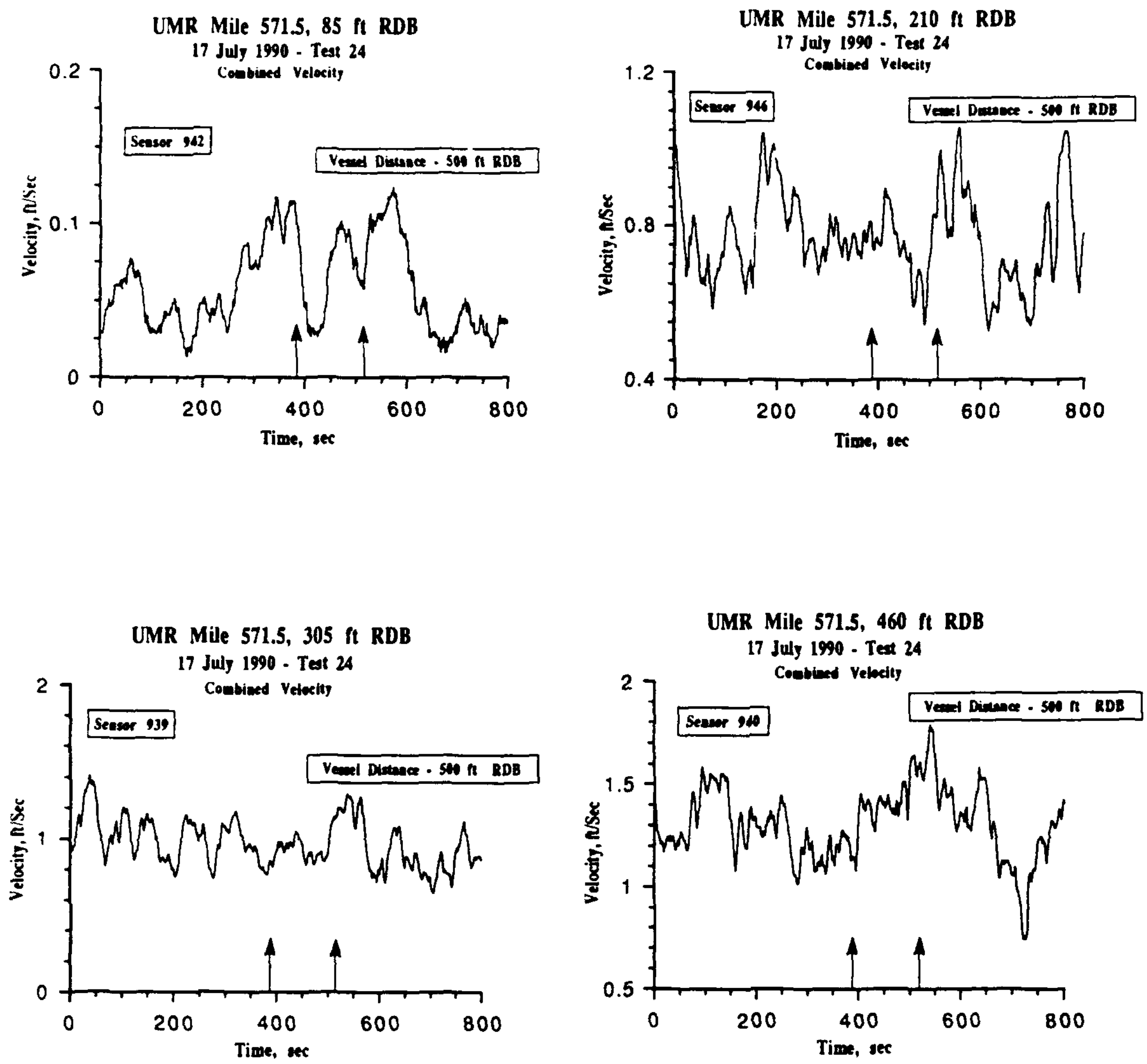

UMR Mile 571.5, 85 ft RDB
17 July 1990 - Test 24
Combined Velocity
Sensor 942
Vessel Distance - 500 ft RDB
Velocity, ft/Sec
Time, sec
0.2
0.1
0
0
200
400
600
800
UMR Mile 571.5, 210 ft RDB
17 July 1990 - Test 24
Combined Velocity
Sensor 946
Vessel Distance - 500 ft RDB
Velocity, ft/Sec
Time, sec
1.2
0.8
0.4
0
200
400
600
800
UMR Mile 571.5, 305 ft RDB
17 July 1990 - Test 24
Combined Velocity
Sensor 939
Vessel Distance - 500 ft RDB
Velocity, ft/Sec
Time, sec
2
1
0
0
200
400
600
800
UMR Mile 571.5, 460 ft RDB
17 July 1990 - Test 24
Combined Velocity
Sensor 940
Vessel Distance - 500 ft RDB
Velocity, ft/Sec
Time, sec
2
1.5
1
0.5
0
200
400
600
800

Figure E68

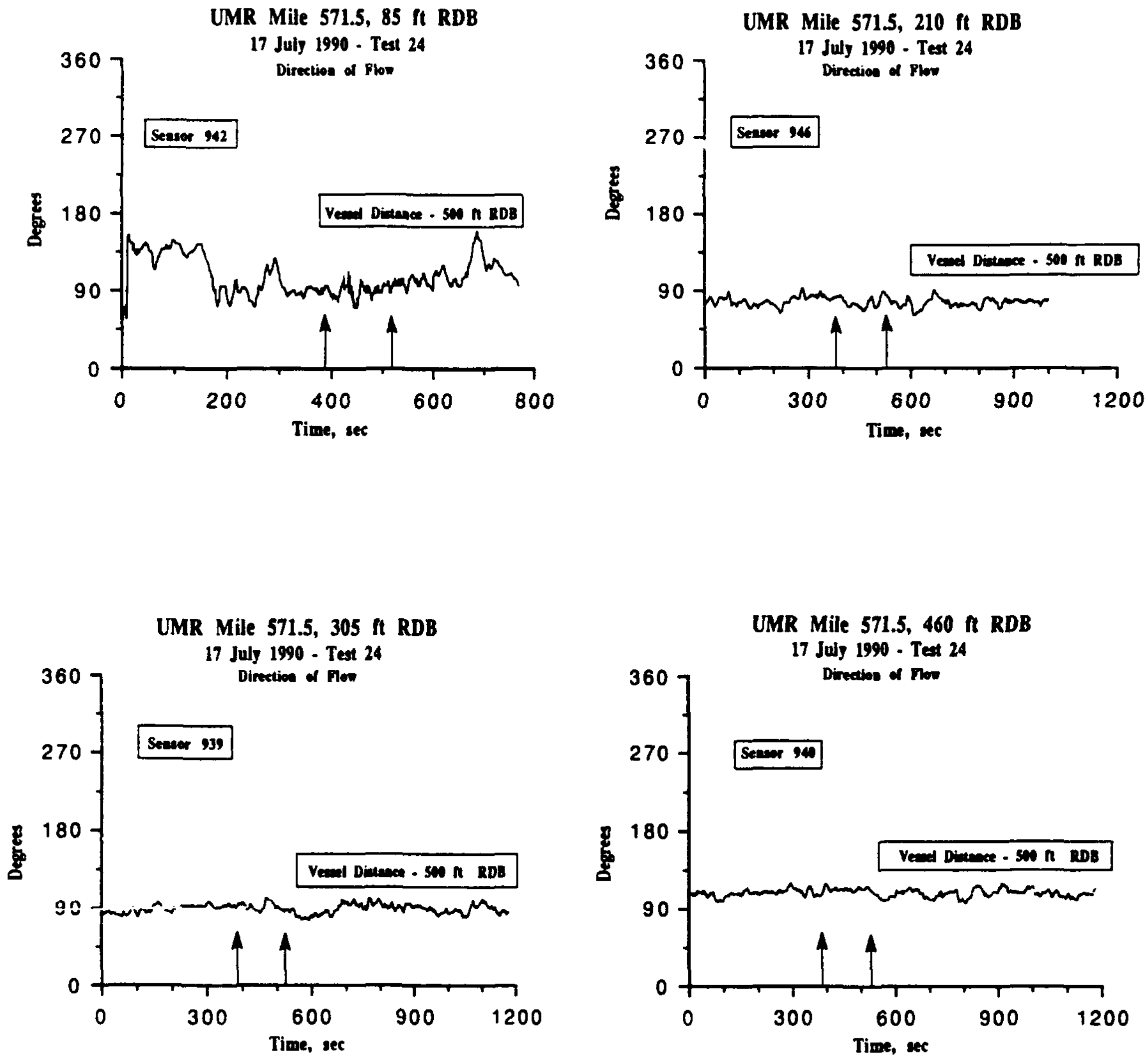

UMR Mile 571.5, 85 ft RDB
17 July 1990 - Test 24
Direction of Flow
Sensor 942
Vessel Distance - 500 ft RDB
Degrees
Time, sec
UMR Mile 571.5, 210 ft RDB
17 July 1990 - Test 24
Direction of Flow
Sensor 946
Vessel Distance - 500 ft RDB
Degrees
Time, sec
UMR Mile 571.5, 305 ft RDB
17 July 1990 - Test 24
Direction of Flow
Sensor 939
Vessel Distance - 500 ft RDB
Degrees
Time, sec
UMR Mile 571.5, 460 ft RDB
17 July 1990 - Test 24
Direction of Flow
Sensor 940
Vessel Distance - 500 ft RDB
Degrees
Time, sec

Figure E69